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D E C L A R A T I O N

I, Shinichi Usui, a Japanese Patent Attorney registered No. 9694, of Okabe International Patent Office at No. 602, Fuji Bldg., 2-3, Marunouchi 3-chome, Chiyoda-ku, Tokyo, Japan, hereby declare that I have a thorough knowledge of Japanese and English languages, and that the attached pages contain a correct translation into English of the priority documents of Japanese Patent Application No. 8-0446741 filed on February 8, 1996 in the name of CANON KABUSHIKI KAISHA.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made, are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

signed this 25th day of January, 2000

Shinichi Usui

PATENT OFFICE
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This is to certify that the annexed is a true copy of the following application as filed with this Office.

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Applicant(s): CANON KABUSHIKI KAISHA

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[Title of the Invention] Scanning Optical Apparatus and Multibeam Scanning Optical Apparatus

[What is claimed is:]

[Claim 1] A scanning optical apparatus in which a beam of light emitted from a light source means is imaged into a linear shape long in the main scanning direction on a deflecting surface of a deflecting element through a first optical element and a second optical element, and said beam of light deflected by said deflecting element is imaged into a spot-like shape on a surface to be scanned through a third optical element, so as to scan said surface to be scanned, characterized in that:

said third optical element comprises a single lens, the both opposite lens surfaces of said single lens comprise a toric surface of an aspherical surface shape in the main scanning plane, and the curvature of said opposite lens surfaces in the sub scanning plane is continuously varied from the on-axis toward the off-axis in an effective portion of the lens, thereby preventing a change of the F number in the sub scanning direction from being caused by the image height of the beam of light incident on said surface to be scanned.

[Claim 2] A scanning optical apparatus according to Claim 1, wherein said light source means has a plurality of light source units capable of being independently modulated.

[Claim 3] A scanning optical apparatus according to Claim 1 or 2, wherein when the curve amounts of the loci, in the main scanning plane, of the front side principal plane and the rear side principal plane of said third optical element in the sub scanning direction (the difference in the direction of the optical axis between the most off-axis principal plane position and the on-axis principal plane position) are xm and xu, respectively, the following condition is satisfied:

$$xm \leq dx \leq xu,$$

where

$$dx = \frac{Ipri \cdot Epri(\cos\theta img - \cos\theta por)}{Ipri \cdot \cos\theta por + Epri \cdot \cos\theta img}$$

Ipri is the distance from the deflecting surface of the deflecting element in the on-axis beam to the front side principal plane in the sub scanning direction;

Epri is the distance from the rear side principal

plane in the sub scanning direction in the on-axis beam to the surface to the scanned;

θpor is the angle formed in the main scanning plane by the most off-axis beam deflected by the deflecting element with respect to the optical axis;

θimg is the angle formed in the main scanning plane by the most off-axis beam incident on the surface to be scanned with respect to the optical axis.

[Claim 4] A scanning optical apparatus according to Claim 1 or 2, wherein the sign of the curvature of at least one of the opposite lens surfaces of the single lens constituting said third optical element in the sub scanning plane is reversed from the on-axis toward the off-axis.

[Claim 5] A scanning optical apparatus according to Claim 1 or 2, wherein said third optical element is made by plastic molding.

[Claim 6] A scanning optical apparatus according to Claim 1 or 2, wherein said third optical element is made by glass molding.

[Claim 7] A multibeam scanning optical apparatus

in which a plurality of beams of light emitted from a light source means and independently modulated are imaged into a linear shape long in the main scanning direction on a deflecting surface of a deflecting element through a first optical element and a second optical element, and said plurality of beams of light deflected by said deflecting element are imaged into a spot-like shape on a surface to be scanned through a third optical element, so as to scan said surface to be scanned, characterized in that:

said third optical element comprises a single lens, and the curvature of opposite lens surfaces of said single lens in the sub scanning direction is continuously varied from the on-axis toward the off-axis, thereby preventing a change of the F number in the sub scanning direction from being caused by the image height of the beams of light incident on said surface to be scanned.

[Claim 8] A multibeam scanning optical apparatus according to Claim 7, wherein when the maximum value and minimum value of the F number of the beam of light incident on the surface to be scanned in the sub scanning direction are Fmax and Fmin, respectively, the curvatures of the opposite lens surfaces of the single

lens constituting said third optical element in the sub scanning direction are continuously varied from the on-axis toward the off-axis so as to satisfy the condition that

Fmin/Fmax ≥ 0.9.

[Claim 9] A multibeam scanning optical apparatus according to Claim 7, wherein the sign of the curvature of at least one of the opposite lens surfaces of the single lens constituting said third optical element in the sub scanning direction is reversed from the on-axis toward the off-axis.

[Claim 10] A multibeam scanning optical apparatus according to Claim 7, wherein the curvatures of the opposite lens surfaces of the single lens constituting said third optical element in the sub scanning direction are varied asymmetrically with respect to the optical axis from the on-axis toward the off-axis.

[Claim 11] A multibeam scanning optical apparatus according to Claim 7, wherein said third optical element is made by plastic molding.

[Claim 12] A multibeam scanning optical apparatus

according to Claim 7, wherein said third optical element is made by glass molding.

[Claim 13] A multibeam scanning optical apparatus in which a plurality of beams of light emitted from a light source means and independently modulated are imaged into a linear shape long in the main scanning direction on a deflecting surface of a deflecting element through a first optical element and a second optical element, and said plurality of beams of light deflected by said deflecting element are imaged into a spot-like shape on a surface to be scanned through a third optical element, so as to scan said surface to be scanned, characterized in that:

said third optical element comprises at least two lenses, and the curvature of at least two lens surfaces of said two lenses in the sub scanning direction is continuously varied from the on-axis toward the off-axis, thereby preventing a change of the F number in the sub scanning direction from being caused by the image height of the beams of light incident on said surface to be scanned.

[Claim 14] A multibeam scanning optical apparatus according to Claim 13, wherein when the maximum value

and minimum value of the F number of the beam of light incident on said surface to be scanned in the sub scanning direction are Fmax and Fmin, respectively, the curvatures of at least two lens surfaces of the two lenses constituting said third optical element in the sub scanning direction are continuously varied from the on-axis toward the off-axis so as to satisfy the condition that

$$Fmin/Fmax \geq 0.9.$$

[Claim 15] A multibeam scanning optical apparatus according to Claim 13, wherein the sign of the curvature of at least one lens surface of said two lenses constituting said third optical element in the sub scanning direction is reversed from the on-axis toward the off-axis.

[Claim 16] A multibeam scanning optical apparatus according to Claim 13, wherein the curvatures of at least two lens surfaces of the two lenses constituting said third optical element in the sub scanning direction are varied asymmetrically with respect to the optical axis from the on-axis toward the off-axis.

[Claim 17] A multibeam scanning optical apparatus

according to Claim 13, wherein at least one of the two lenses constituting said third optical element is made by plastic molding.

[Claim 18] A multibeam scanning optical apparatus according to Claim 13, wherein at least one of the two lenses constituting said third optical element is made by glass molding.

[Detailed description of the Invention]

[0001]

[Field of the Industrial Utilization]

This invention relates to a scanning optical apparatus and a multibeam scanning optical apparatus, and particularly to a scanning optical apparatus and a multibeam scanning optical apparatus suitable for use, for example, in an apparatus such as a laser beam printer (LBP) or a digital copying apparatus having the electrophotographic process adapted to deflect and reflect a beam of light optically modulated and emitted from light source means by a light deflector (deflecting element) comprising a rotatable polygon mirror or the like, thereafter optically scan a surface to be scanned through an imaging optical system having the fθ characteristic (fθ lens) and record image

information.

[0002]

[Prior Art]

Heretofore, in the scanning optically apparatus of a laser beam printer or the like, a beam of light optically modulated and emerging from light source means in conformity with an image signal has been periodically deflected by a light deflector comprising, for example, a rotatable polygon mirror and has been converged into a spot-like shape on the surface of a photosensitive recording medium (photosensitive drum) having the $f\theta$ characteristic, and that surface has been optically scanned to thereby effect image recording.

[0003]

Figure 25 of the accompanying drawings is a schematic view of the essential portions of a scanning optical apparatus according to the prior art.

[0004]

In Figure 25, a divergent beam of light emitted from light source means 61 is made into a substantially parallel beam of light by a collimator lens 62, and the beam of light (the quantity of light) is limited by a stop 63 and enters a cylindrical lens 64 having predetermined refractive power only in a sub scanning direction. Of the parallel beam of light having

entered the cylindrical lens 64, that part in a main scanning section intactly emerges in the state of a parallel beam of light. Also, that part in a sub scanning section converges and is imaged as a substantially linear image on the deflecting surface (reflecting surface) 65a of a light deflector 65 comprising a rotatable polygon mirror.

[0005]

Here, the main scanning section refers to a beam section the beam of light deflected and reflected by the deflecting surface of the light deflector forms with time. Also, the sub scanning section refers to a section containing the optical axis of an fθ lens and orthogonal to the main scanning section.

[0006]

The beam of light deflected and reflected by the deflecting surface 65a of the light deflector 65 is directed onto the surface of a photosensitive drum 68 as a surface to be scanned through an imaging optical system (fθ lens) 66 having the fθ characteristic, and the light deflector 65 is rotated in the direction of arrow A to thereby optically scan the surface of the photosensitive drum 68 and effect the recording of image information.

[0007]

[Problems to be solved by the Invention]

To effect the highly accurate recording of image information in a scanning optical apparatus of this kind, it is necessary that curvature of image field be well corrected over the entire area of a surface to be scanned and a spot diameter be uniform and that the angle and image height of the incident light have distortion (fθ characteristic) in which they are in a proportional relation. A scanning optical apparatus satisfying such optical characteristics or the correcting optical system (fθ lens) thereof has heretofore been variously proposed.

[0008]

On the other hand, with the tendency of laser beam printers, digital copying apparatuses, etc. toward compactness and lower cost, similar things are required of the scanning optical apparatus.

[0009]

As an apparatus which makes these requirements compatible, a scanning optical apparatus in which the fθ lens is comprised of a single lens is variously proposed, for example, in Japanese Patent Publication No. 61-48684, Japanese Laid-Open Patent Application No. 63-157122, Japanese Laid-Open Patent Application No. 4-104213, Japanese Laid-Open Patent Application No. 4-

50908, etc.

[0010]

Of these publications, in Japanese Patent Publication No. 61-48684 and Japanese Laid-Open Patent Application No. 63-157122, a concave single lens as on fθ lens is used on the light deflector side to converge a parallel beam of light from a collimator lens on the surface of a recording medium. Also, in Japanese Laid-Open Patent Application No. 4-104213, as fθ lenses, a concave single lens and a toroidal-surfaced single lens are used on the light deflector side and the image plane side, respectively, to make a beam of light converted into convergent light by a collimator lens enter the fθ lenses. Also, in Japanese Laid-Open Patent Application No. 4-50908, a single lens introducing a high-order aspherical surface into a lens surface is used as an fθ lens to make a beam of light converted into convergent light by a collimator lens enter the fθ lens.

[0011]

However, in the scanning optical apparatuses according to the prior art described above, according to Japanese Patent Publication No. 61-48684, curvature of image field in the sub scanning direction remains and a parallel beam of light is imaged on the surface

to be scanned, and this has led to the problem that the distance from the fθ lens to the surface to the scanned becomes a focal length f and is long and it is difficult to construct a compact scanning optical apparatus. In Japanese Laid-Open Patent Application No. 63-157122, the thickness of the fθ lens is great, and this has led to the problem that manufacture by molding is difficult and this makes a factor of increased cost. Japanese Laid-Open Patent Application No. 4-104213 has suffered from the problem that distortion remains. In Japanese Laid-Open Patent Application No. 4-50908, an fθ lens having a high-order aspherical surface is used and aberrations are corrected well, but there has been the problem that jitter of a period corresponding to the number of polygon surfaces occurs due to the mounting error of a polygon mirror which is a light deflector.

[0012]

Further, problems common to these fθ lenses each comprised of a single lens has included the problem that due to the non-uniformity of the lateral magnification in the sub scanning direction between the light deflector and the surface to be scanned, the spot diameter in the sub scanning direction changes depending on image height.

[0013]

(A) and (B) of Figure 26 of the accompanying drawings are cross-sectional views of the essential portions of a single beam scanning optical apparatus in the main scanning direction and the sub scanning direction, respectively, which apparatus has been proposed by the inventor in Japanese Patent Application No. 6-239386, and show changes in the spot diameter (F number) in the sub scanning direction due to image height. In these views, the same elements as the elements shown in Figure 25 are given the same reference numerals.

[0014]

Usually, in a plane inclination correcting optical system, it is necessary to bring the deflecting surface of a light deflector and a surface to be scanned into an optically conjugate relation (imaging relation) in order to optically correct the plane inclination of the deflecting surface. Accordingly, in an fθ lens having a predetermined lens shape in the main scanning section as in the aforedescribed examples of the prior art, lateral magnification is high on the axis (on-axis beam 21) as indicated at (1) in (B) of Figure 26, and lateral magnification becomes low off the axis (most off-axis beam 22) as indicated at (2) in (B) of Figure

26 (there is also a case where this becomes converse depending on the lens shape in the main scanning section).

[0015]

Thus, irregularity occurs to the lateral magnification in the sub scanning direction depending on the lens shape of the fθ lens in the main scanning plane thereof and a change in the spot diameter in the sub scanning direction due to image height occurs.

[0016]

On the other hand, the ability of higher speed scanning is required of a scanning optical apparatus for use in an LBP because of the tendency of the LBP toward higher speed and higher accuracy, and from limitations such as the number of revolutions of a motor which is scanning means and the number of surfaces of a polygon mirror which is deflecting means, particularly the demand for a multibeam scanning optical apparatus capable of scanning a plurality of beams of light at a time is growing.

[0017]

The above-described non-uniformity of the lateral magnification in the sub scanning direction makes the curve of the scanning line when the position of a light source (light source unit) is off the optical axis in Z

direction indicated in Figure 2 and therefore, an optical system such as a multibeam scanning optical system (multibeam scanning optical apparatus) which scans a surface to be scanned at a time by the use of a plurality of beams of light off the optical axis has suffered from the problem that the scanning line bends on the surface to be scanned and as a result, the deterioration of image quality due to pitch irregularity occurs.

[0018]

It is a first object of the present invention to provide a compact scanning optical apparatus suitable for highly accurate printing in which when a beam of light from a light source converted by a collimator lens or the like is to be imaged on a surface to be scanned by an fθ lens through a light deflector, the lens shape (the main scanning plane shape) of the fθ lens in the main scanning plane thereof is optimized to thereby correct curvature of image field, distortion, etc. and the non-uniformity of lateral magnification in the sub scanning direction between the light deflector and the surface to be scanned is eliminated by only the lens shape (the sub scanning plane shape) in the sub scanning plane, independently of the lens shape in the main scanning plane, whereby any change in F number (F

No.) in the sub scanning direction due to image height, i.e., any change in spot diameter, can be suppressed.

[0019]

It is a second object of the present invention to provide a compact multibeam scanning optical apparatus suitable for highly accurate printing in which a plurality of beams of light from a light source converted by a collimator lens or the like is to be imaged on a surface to be scanned by an fθ lens through a light deflector, the lens shape (the main scanning plane shape) of the fθ lens in the main scanning plane thereof is optimized to thereby correct curvature of image field, distortion, etc. and the non-uniformity of lateral magnification in the sub scanning direction between the light deflection and the surface to be scanned is eliminated by only the lens shape (the sub scanning plane shape) in the sub scanning plane, independently of the lens shape in the main scanning plane, whereby any change F number (F No.) in the sub scanning direction in spot diameter, can be suppressed and a beam of light from the light source which is off the optical axis in the sub scanning direction can also be scanned highly accurately without the curve of the scanning line occurring.

[0020]

[Means for solving the Problems]

The scanning optical apparatus of the present invention is

(1-1) a scanning optical apparatus in which a beam of light emitted from light source means is imaged into a linear shape long in the main scanning direction on the deflecting surface of a deflecting element through a first optical element and a second optical element and the beam of light deflected by the deflecting element is imaged into a spot-like shape on a surface to be scanned through a third optical element to thereby scan the surface to be scanned, characterized in that the third optical element comprise a single lens, the opposite lens surfaces of the single lens both comprise a tori surface of an aspherical shape in the main scanning plane, and the curvature thereof in the sub scanning section is continuously varied from the on-axis toward the off-axis in the effective portion of the lens to thereby suppress any change of F number in the sub scanning direction due to the image height of the beam of light incident on the surface to be scanned.

[0021]

Particularly, it is characterized in

(1-1-1) that the light source means has a

plurality of light source means has a plurality of light source units capable of being independently modulated,

(1-1-2) that when the curve amounts of the loci, in the main scanning plane, of the front side principal plane and the rear side principal plane of the third optical element in the sub scanning direction (the difference in the direction of the optical axis between the most off-axis principal plane position and the on-axis principal plane position) are xm and xu, respectively, the following condition $xm \leq dx \leq xu$, is satisfied:

where

[0022]

[Numerical Formula 2]

$$dx = \frac{Ipri \cdot Epri(\cos\theta img - \cos\theta por)}{Ipri \cdot \cos\theta por + Epri \cdot \cos\theta img}$$

Ipri: the distance from the deflecting surface of the deflecting element in the on-axis beam to the front side principal plane in the sub scanning direction;

Epri: the distance from the rear side principal plane in the sub scanning direction in the on-axis beam to the surface to the scanned;

θpor: the angle formed in the main scanning plane by the most off-axis beam deflected by the deflecting element with respect to the optical axis;

θimg: the angle formed in the main scanning plane by the most off-axis beam incident on the surface to be scanned with respect to the optical axis;

(1-1-3) that the sign of the curvature of at least one of the opposite lens surfaces of the single lens constituting the third optical element in the subscanning plane is reversed from the on-axis toward the off-axis; and

(1-1-4) that the third optical element is made by plastic molding; or

(1-1-5) that the third optical element is made by glass molding.

[0023]

The multibeam scanning optical apparatus of the present invention is

(2-1) a multibeam scanning optical apparatus in which a plurality of independently modulated beams of light emitted from light source means are imaged into linear shapes long in the main scanning direction on the deflecting surface of a deflecting element through a first optical element and a second element and the plurality of beams of light deflected by the deflecting

element are imaged into a spot-like shape on a surface to be scanned through a third optical element to thereby scan the surface to be scanned,

characterized in that the third optical element comprises a single lens, and the curvatures of the opposite lens surfaces of the single lens in the sub scanning direction are continuously varied from the on-axis toward the off-axis to thereby suppress any change of F number in the sub scanning direction due to the image height of the beam light incident on the surface to be scanned.

[0024]

Particularly, it is characterized in

(2-1-1) that when the maximum value and minimum value of the F number of the beam of light incident on the surface to be scanned in the sub scanning direction are Fmax and Fmin, respectively, the curvatures of the opposite lens surfaces of the single lens constituting the third optical element in the sub scanning direction are continuously varied from the on-axis toward the off-axis so as to satisfy the condition that

$Fmin/Fmax \geq 0.9$,

(2-1-2) that the sign of the curvature of at least one of the opposite lens surfaces of the single lens constituting the third optical element in the sub

scanning direction is reversed from the on-axis toward the off-axis,

(2-1-3) that the curvatures of the opposite lens surfaces of the single lens constituting the third optical element in the sub scanning direction are varied asymmetrically with respect to the optical axis from the on-axis toward the off-axis, and

(2-1-4) that the third optical element is made by plastic molding, or

(2-1-5) that the third optical element is made by glass molding.

[0025]

(2-2) a multibeam scanning optical apparatus in which a plurality of independently modulated beams of light emitted from light source means are imaged into a linear shape long in the main scanning direction on the deflecting surface of a deflecting element through a first optical element and a second optical element and the plurality of beams of light deflected by the deflecting element are imaged into a spot-like shape on a surface to be scanned through a third optical element is characterized in

that the third optical element is comprised of at least two lenses, and the curvatures of at least two lens surfaces of the two lenses in the sub scanning

direction are continuously varied from the on-axis toward the off-axis to thereby suppress any change of F number in the sub-scanning direction due to the image height of the beam of light incident on the surface to be scanned.

[0026]

Particularly, it is characterized in

(2-2-1) that when the maximum value and minimum value of the F number of the beam of light incident on the surface to be scanned in the sub-scanning direction are Fmax and Fmin, respectively, the curvatures of at least two lens surfaces of the two lenses constituting the third optical element in the sub scanning direction are continuously varied from the on-axis toward the off-axis so as to satisfy the condition that

$Fmin/Fmax \geq 0.9$,

(2-2-2) that the sign of the curvature of at least one lens surface of the two lenses constituting the third optical element in the sub scanning direction is reversed from the on-axis toward the off-axis,

(2-2-3) that the curvatures of at least two surfaces of the two lenses constituting the third optical element in the sub scanning direction are varied asymmetrically with respect to the optical axis from the on-axis toward the off-axis, and

(2-2-4) that at least one of the two lenses constituting the third optical element is made by plastic molding, or

(2-2-5) that at least one of the two lenses constituting the third optical element is made by glass molding.

[0027]

[Embodiments]

Before some embodiments of the scanning optical apparatus of the present invention are described, means for achieving the objects of the present invention will first be described. To achieve the above-described objects in the scanning optical apparatus, it is necessary to optimize the lens shape of the fθ lens and to uniformize the lateral magnifications in the sub scanning direction on the axis and off the axis. Figure 3 is a cross-sectional view of the essential portions in the main scanning direction between the light deflector (deflecting element) of the scanning optical apparatus and the surface to be scanned. To uniformize the lateral magnifications in the sub scanning direction on the axis and off the axis, it is necessary to determine the principal plane position so that the ratios of the lengths of optical path on the axis and off the axis may be equal to each other.

[0028]

Accordingly, the principal plane position of the fθ lens in the sub scanning direction is determined so as to satisfy the following conditions:

Ipri : Epri = Imar : Emar

Ipri • Emar = Epri • Imar ... (a)

where

Ipri: the distance from the deflecting surface of the light deflector to the front side principal plane in the sub scanning direction in the on-axis beam;

Epri: the distance from the rear side principal plane in the sub scanning direction to the surface to be scanned in the on-axis beam;

Imar: the distance from the deflecting surface of the light deflector to the front side principal plane in the sub scanning direction in the most off-axis beam;

Emar: the distance from the rear side principal plane in the sub scanning direction to the surface to be scanned in the most off-axis beam.

[0029]

Generally, the off-axis beam is refracted in the direction of the optical axis in the main scanning plane in order to satisfy the fθ characteristic and

therefore, a focus 71 in the main scanning plane of the principal plane in the sub scanning direction for satisfying the above expression (a) is a plane curved toward a light deflector 5 off the axis as shown in Figure 27. Here, when the curve amount on the most off-axis is dx,

$$Emar = (Epri+dx)/\cos\theta img$$

$$Imar = (Ipri-dx)/\cos\theta por$$

and consequently,

$$Ipri(Epri+dx)/\cos\theta img = Epri(Ipri-dx)/\cos\theta img$$

$$dx(Ipri\bullet\cos\theta por+Epri\bullet\cos\theta img)$$

$$= Ipri\bullet Epri(\cos\theta img-\cos\theta por)$$

[0030]

[Numerical Formula 3]

$$dx=\frac{Ipri\cdot Epri(\cos\theta img-\cos\theta por)}{Ipri\cdot\cos\theta por+Epri\cdot\cos\theta img} \quad \ldots \text{(b)}$$

where

θpor: the angle formed in the main scanning plane by the most off-axis beam deflected by the light deflector with respect to the optical axis of the fθ lens;

θimg: the angle formed in the main scanning plane by the most off-axis beam incident on the surface to be scanned with respect to the optical axis of the

fθ lens.

[0031]

Accordingly, to uniformize the lateral magnification in the sub scanning direction, it is necessary to set the curve amount dx of the locus of the principal plane in the sub scanning direction to a value derived from the above expression (b).

[0032]

That is, when in an actual scanning optical apparatus, the curve amounts of the loci, in the main scanning plane, of the front side principal plane and the rear side principal plane of an fθ lens in the sub scanning direction (the difference in the direction of the optical axis between the most off-axis principal plane position and the on-axis principal plane position) are xm and xu, respectively, it is desirable to determine the principal plane position so as to satisfy the condition that

$$xm \leq dx \leq xu. \qquad \ldots (1)$$

[0033]

If the above conditional expression (1) is departed from, irregularity will occur to the lateral magnification in the sub scanning direction and the change in spot diameter due to image height will become great, and this will pose a problem in practice.

[0034]

Next, as regards a method of changing the principal plane position in the sub scanning direction, the deflecting surface of the light deflector and the surface to be scanned are brought into optically conjugate relationship with each other in the sub scanning direction of the fθ lens as previously described to thereby effect the correction of plane inclination and therefore, the refractive power itself of the fθ lens cannot be varied.

[0035]

Accordingly, the first lens surface (R1 surface) and the second lens surface (R2 surface) of the fθ lens in the sub scanning direction are bent to thereby effect the movement of the principal plane position. By the bending, the principal plane of the lens can be moved without the refractive power of the lens itself being changed and therefore, the meridian line r is continuously changed from the on-axis toward the off-axis and an optimum lens shape can be provided depending on location, whereby the lateral magnification in the sub scanning direction can be uniformized.

[0036]

By optimizing the lens shape of the fθ lens in

this manner, the F number (F No.) in the sub scanning direction of the beam of light incident on the surface to be scanned can be uniformized, and the variation in the spot diameter in the sub scanning direction due to image height which has heretofore been a problem peculiar to a single-lens fθ lens can be minimized.

[0037]

Also for a beam of light emerging from a light source (light source unit) off the optical axis, the surface to be scanned can be highly accurately scanned without causing the curve of the scanning line, whereby there can be provided a scanning optical apparatus suitable also for multibeam scanning.

[0038]

Some embodiments of the present invention will now be described.

[0039]

(A) and (B) of Figure 1 are cross-sectional views of Embodiment 1 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[0040]

In these views, reference numeral 1 designates light source means (a light source unit) comprising, for example, a semiconductor laser.

[0041]

Reference numeral 2 denotes a collimator lens as a first optical element which converts a divergent beam of light emitted from the light source means 1 into a convergent beam of light. Reference numeral 3 designates an aperture stop which regularizes the diameter of the beam of light passing therethrough.

[0042]

Reference numeral 4 denotes a cylindrical lens as a second optical element which has predetermined refractive power only in the sub scanning direction and causes the beam of light passed through the aperture stop 3 to be imaged as a substantially linear image on the deflecting surface 5a of a light deflector (deflecting element) 5 which will be described later in the sub scanning section.

[0043]

Reference numeral 5 designates a light deflector as a deflecting element which comprises, for example, a polygon mirror (rotatable polygon mirror) and is rotated at a predetermined speed in the direction of arrow A by drive means (not shown) such as a motor.

[0044]

Reference numeral 6 denotes an fθ lens (imaging optical system) as a third optical element comprising a

lens having the fθ characteristic and disposed more toward the light deflector 5 side than the intermediate portion between the light deflector 5 and a photosensitive drum surface 8 as a surface to be scanned. In the present embodiment, the opposite lens surface of the fθ lens 6 both comprise a toric surface which is aspherical in the main scanning plane, and continuously varies the curvature in the sub scanning plane (a plane containing the optical axis of the third optical element and orthogonal to the main scanning plane) from the on-axis toward the off-axis in the effective portion of the lens. Thereby, in Embodiment 1, the change in F number (F No.) in the sub scanning direction due to the image height of the beam of light incident on the surface 8 to be scanned, i.e., the change in spot diameter, is minimized. The fθ lens 6 causes the beam of light based on image information deflected and reflected by the light deflector 5 to be imaged on the photosensitive drum surface 8 and corrects the plane inclination of the deflecting surface of the light deflector 5.

[0045]

In Embodiment 1, the fθ lens 6 may be made by plastic molding or may be made by glass molding.

[0046]

In Embodiment 1, the divergent beam of light emitted from the semiconductor laser 1 is converted into a convergent beam of light by the collimator lens 2, and this beam of light (the quantity of light) is limited by the aperture stop 3 and enters the cylindrical lens 4. The beam of light having entered the cylindrical lens 4, in the main scanning section, emerges therefrom intactly in that state. Also, in the sub scanning section, it converges and is imaged as a substantially linear image (a linear image long in the main scanning direction) on the deflecting surface 5a of the light deflector 5. The beam of light deflected and reflected by the deflecting surface 5a of the light deflector 5 is directed onto the photosensitive drum surface 8 through the fθ lens 6 having different refractive powers in the main scanning direction and the sub scanning direction, and scans the photosensitive drum surface 8 in the direction of arrow B by the light deflector 5 being rotated in the direction of arrow A. Thereby, image recording is effected on the photosensitive drum 8 which is a recording medium.

[0047]

In Embodiment 1, the lens shape of the fθ lens in the main scanning direction is an aspherical surface

shape which can be represented by a function up to the tenth-order, and the lens shape in the sub scanning direction is comprised of a spherical surface continuously varying in the direction of image height. The lens shape, when for example, the point of intersection between the fθ lens and the optical axis is the origin and the direction of the optical axis is the X-axis and the axis orthogonal to the optical axis in the main scanning plane is the Y-axis and the axis orthogonal to the optical axis in the sub scanning plane is the Z-axis, is such that the generating-line direction corresponding to the main scanning direction can be represented by the following expression:

[0048]

[Numerical Formula 4]

$$X=\frac{Y^2/R}{1+(1-(1+K)(Y/R)^2)^{1/2}}$$

$$+B_4Y^4+B_6Y^6+B_8Y^8+B_{10}Y^{10}, \quad ..(c)$$

(where R is the radius of curvature, K, B_4 , B_6, B_8 and B_{10} are aspherical surface coefficients) and the meridian-line direction corresponding to the sub scanning direction (the direction orthogonal to the main scanning direction containing the optical axis) can be represented by the following expression:

[0049]

[Numerical Formula 5]

$$S=\frac{Z^2/r'}{1+(1-(Z/r')^2)^{1/2},} \quad \ldots \text{ (d)}$$

(where $r' = r(1+D_2Y^2+D_4Y^4+D_6Y^6+D_8Y^8+D_{10}Y^{10})$.

[0050]

Table 1 below shows the optical arrangement in Embodiment 1 and the aspherical surface coefficients of the fθ lens 6.

[0051]

[Table 1]

Table 1

			shape of fθ lens		
wavelength used	λ(nm)	780		1st surface	2nd surface
refractive index of fθ lens	n	1.519	R	6.7814E+01	1.6154E+02
angle of incidence on polygon	θi	-90	K	-1.6787E+01	-1.0814E+02
maximum angle of emergence from polygon	θmax	45	B4	-9.8604E-07	-2.2909E-06
polygon - fθ lens	e	36	B6	1.5479E-11	7.1426E-10
center thickness of fθ lens	d	11	B8	8.7055E-14	-3.2030E-13
fθ lens - surface to be scanned	Sk	110.5	B10	-4.7942E-18	7.9836E-17
maximum effective diameter of fθ lens	Ymax	42	r	-2.7332E-01	-1.1859E+01
focal length of fθ lens	ft	213.7	D2S	1.2604E-03	4.9796E-04
degree of convergence of collimator polygon - natural converging point	fc	317.3	D4S	1.2255E-06	-2.0734E-07
			D6S	8.4502E-10	2.3479E-10
			D8S	-6.3449E-13	-1.0939E-13
			D10S	1.3148E-15	1.5644E-17
			D2E	9.3936E-04	4.4938E-04
			D4E	2.027E-06	-4.6627E-08
			D6E	7.0546E-10	1.1322E-10
			D8E	-1.2936E-12	-5.8704E-14
			D10E	2.3372E-15	4.3944E-18

Figure 4 is an illustration showing a change of curvature in the sub scanning direction relative to the position of the fθ lens 6 in the lengthwise direction. As shown in Figure 4, the curvature of the meniscus shape is sharp on the axis and becomes plano-convex from the on-axis toward the off-axis. Figure 7 is an illustration showing the aspherical surface shape of the fθ lens 6. In Figure 7, thick solid lines indicate the lens surface shapes in the main scanning direction, and thin solid lines are the loci of the principal plane in the sub scanning direction, and indicate the front side principal plane and the rear side principal plane.

[0052]

In Embodiment 1, the curve amount dx of the locus of the principal plane for suppressing the change of lateral magnification in the sub scanning direction due to image height is

$$dx = 6.50$$

from

$$Ipri = 48.73 \quad Epri = 108.77$$

$$\theta por = 44.4° \quad \theta img = 29.10°.$$

Also, the curve amount xm of the locus of the front side principal plane of the fθ lens 6 in the sub scanning direction and the curve amount xu of the locus

of the rear side principal plane thereof are

$xm = 3.24 \qquad xu = 7.48$

and these values satisfy the aforementioned conditional expression (1) ($xm \leq dx \leq xu$).

[0053]

Thereby, in Embodiment 1, the lateral magnification in the sub scanning direction between the light deflector 5 and the surface 8 to be scanned can be uniformized on the axis and off the axis to a level free of any practical problem, and as shown in Figure 10, the change of the spot diameter in the sub scanning direction due to image height can be minimized. Thereby, there is achieved a scanning optical apparatus which is inexpensive and suitable for highly accurate printing.

[0054]

(A) and (B) of Figure 2 are cross-sectional views of Embodiment 2 of the present invention in the main scanning direction and the sub scanning direction, respectively. In Figure 2, the same elements as the elements shown in Figure 1 are given the same reference numerals.

[0055]

The differences of Embodiment 2 from the aforedescribed Embodiment 1 are that the divergent beam

of light emitted from the semiconductor laser (the light source unit) is converted not into a convergent beam of light but into a parallel beam of light by the collimator lens and that corresponding thereto, the lens shape of the fθ lens is made different. In the other points, the construction and optical action of Embodiment 2 are substantially similar to those of Embodiment 1, whereby a similar effect is obtained.

[0056]

Table 2 below shows the optical arrangement in Embodiment 2 and the aspherical surface coefficients of an fθ lens 26.

[0057]

[Table 2]

Table 2

			shape of fθ lens		
wavelength used	λ(nm)	780		1st surface	2nd surface
refractive index of fθ lens	n	1.519	R	2.2000E+02	−1.1768E+02
angle of incidence on polygon	θi	−60	K	0.0000E+00	0.0000E+00
maximum angle of emergence from polygon	θmax	42	B4	−1.1899E−06	−5.2353E−07
polygon − fθ lens	e	40	B6	3.1847E−10	−8.6171E−11
center thickness of fθ lens	d	15	B8	−2.9372E−14	1.8432E−14
fθ lens − surface to be scanned	Sk	146.45	B10	3.2427E−19	8.4808E−18
maximum effective diameter of fθ lens	Ymax	43	r	−1.1312E+02	−1.7832E+01
focal length of fθ lens	ft	150	d2S	−4.8301E−04	4.5963E−05
			d4S	1.8211E−07	−7.1210E−08
			d6S	−1.0230E−10	1.7390E−11
			d8S	7.2371E−14	−4.3029E−15
			d10S	−2.1962E−17	−1.4545E−19
			d2E	−7.0160E−04	1.1994E−05
			d4E	3.6411E−07	−5.9970E−08
			d6E	−1.0351E−11	−1.7699E−12
			d8E	−7.6585E−14	2.1846E−14
			dD10E	2.0350E−17	−9.2552E−18

Figure 5 is an illustration showing a change of curvature in the sub scanning direction relative to the position of the fθ lens 26 in the lengthwise direction. As shown in Figure 5, the curvature of the meniscus shape becomes sharper from the on axis toward the off-axis. Figure 8 is an illustration showing the aspherical surface shape of the fθ lens 26. In Figure 8, thick solid lines indicate the lens surface shape in the main scanning direction, and thin solid lines are the loci of the principal plane in the sub scanning direction, and indicate the front side principal plane and the rear side principal plane.

[0058]

In Embodiment 2, the curve amount dx of the locus of the principal plane for suppressing the change of lateral magnification in the sub scanning direction due to image height is

$dx = 7.60$

from

$Ipri = 53.94 \quad Epri = 147.51$

$\theta por = 42.0° \quad \theta img = 24.57°$.

Also, the curve amount xm of the locus of the front side principal plane of the fθ lens 26 in the sub scanning direction and the curve amount xu of the locus of the rear side principal plane thereof are

$xm = 7.34$ $xu = 12.31$

and these values satisfy the aforementioned conditional expression (1) ($xm \leq dx \leq xu$).

[0059]

Thereby, in Embodiment 2, as in the aforedescribed embodiment 1, the lateral magnification in the sub scanning direction between the light deflector 25 and the surface 8 to be scanned can be uniformized on the axis and off the axis to a level free of any practical problem, and as shown in Figure 11, the change of the spot diameter in the sub scanning direction due to image height can be minimized. Thereby, there is achieved a scanning optical apparatus which is inexpensive and suitable for highly accurate printing.

[0060]

In Embodiment 2, the divergent beam of light emitted from the semiconductor laser 1 is converted into a parallel beam of light by the collimator lens 2 as previously described and therefore, the jitter by the light deflector is null, and the lens shape, in the main scanning direction, of the lens surface R2 preponderantly creating the power in the sub scanning direction is similar to the shape of the locus of the principal plane for uniformizing the lateral magnification and therefore, the lateral magnification

can be uniformized even if the change of curvature in the meridian-line direction due to image height is small, whereby there can be achieved a scanning optical apparatus suitable for further highly accurate printing.

[0061]

(A) and (B) of Figure 3 are cross-sectional views of Embodiment 3 of the present invention in the main scanning direction and the sub scanning direction, respectively. In these views, the same element as the elements shown in Figure 1 are given the same reference numerals.

[0062]

The differences of Embodiment 3 from the aforedescribed Embodiment 1 are that the apparatus is comprised of a multibeam scanning optical system for scanning a plurality of beams of light emitted from light source means 11 having a plurality of (in Embodiment 3, (two) light source units capable of being independently modulated, at a time, so as to have a predetermined interval therebetween on the surface to be scanned, and that correspondingly thereto, the lens shape of the fθ lens in the meridian-line direction (the sub scanning direction) is made different. In the other points, the construction and optical action of

Embodiment 3 are substantially similar to those of the aforedescribed Embodiment 1, whereby a similar effect is obtained. The above-described plurality of light source units are disposed at a predetermined interval in the sub scanning direction.

[0063]

Table 3 below shows the optical arrangement in Embodiment 3 and the aspherical surface coefficients of an fθ lens 36.

[0064]

[Table 3]

Table 3

				shape of fθ lens	
wavelength used	λ(nm)	780		1st surface	2nd surface
refractive index of fθ lens	n	1.519	R	6.7814E+01	1.6154E+02
angle of incidence on polygon	θi	-90	K	-1.6787E+01	-1.0814E+02
maximum angle of emergence from polygon	θmax	45	B4	-9.8604E-07	-2.2909E-06
polygon - fθ lens	e	36	B6	1.5479E-11	7.1426E-10
center thickness of fθ lens	d	11	B8	8.7055E-14	-3.2030E-13
fθ lens - surface to be scanned	Sk	110.5	B10	-4.7942E-18	7.9836E-17
maximum effective diameter of fθ lens	Ymax	42	r	-2.8363E+01	-1.1966E+01
focal length of fθ lens	ft	213.7	d2S	5.4992E-05	4.4462E-05
degree of convergence of collimator polygon - natural converging point	fc	317.3	d4S	-2.2581E-08	-2.7866E-08
			d6S	9.5892E-12	2.5295E-11
			d8S	-1.9648E-15	-1.0163E-14
			d10S	2.7992E-19	1.9816E-18
			d2E	4.3102E-05	3.9194E-05
			d4E	1.7579E-08	-1.2704E-08
			d6E	-3.6419E-11	1.1605E-11
			d8E	2.1285E-14	-3.3827E-15
			d10E	-4.6427E-18	8.2100E-20

In Embodiment 3, the lens shape of at least one of the lens surfaces of the fθ lens 36 in the meridian-line direction is set so that the sign of curvature may be reversed from on the on-axis toward the off-axis. Therefore, the meridian-line direction of the fθ lens 36 corresponding to the sub scanning direction is represented by the following expression:

[0065]

[Numerical Formula 6]

$$S=\frac{Z^2/r'}{1+(1-(Z/r')^2)^{1/2}}, \quad \ldots \text{(e)}$$

where $r' = r+d_2Y^2+d_4Y^4+d_6Y^6+d_8Y^8+d_{10}Y^{10}$. Also, the generating-line direction corresponding to the main scanning direction is represented by expression (c) as in the aforedescribed Embodiment 1.

[0066]

Figure 6 is an illustration showing a change of curvature in the sub scanning direction relative to the position of the fθ lens 36 in Embodiment 3 in the lengthwise direction. As shown in Figure 6, on the lens surface R1, the sign of curvature in the sub scanning direction is reversed from on the on-axis toward the off-axis, and the meniscus shape on the axis changes into a biconvex shape off the axis. Figure 9

is an illustration showing the aspherical surface shape of the fθ lens 36. In Figure 9, thick solid lines indicate the lens surface shape in the main scanning direction, and thin solid lines are the loci of the principal plane in the sub scanning direction, and indicate the front side principal plane and the rear side principal plane.

[0067]

In Embodiment 3, the curve amount dx of the locus of the principal plane for suppressing the change of lateral magnification in the sub scanning direction due to image height is

$$dx = 6.50$$

from

$$Ppri = 48.73 \quad Epri = 108.77$$

$$\theta por = 44.4° \quad \theta img = 29.10°.$$

Also, the curve amount xm of the locus of the front side principal plane of the fθ lens 36 in the sub scanning direction and the curve amount xu of the locus of the rear side principal plane thereof are

$$xm = 4.93 \quad xu = 9.10$$

and these values satisfy the aforementioned conditional expression (1) ($xm \le dx \le xu$).

[0068]

Thus, in Embodiment 3, as in the aforedescribed

Embodiments 1 and 2, the lateral magnification in the sub scanning direction between the light deflector 5 and the surface 8 to be scanned can be uniformized to a level free of any practical problem on the axis and off the axis, and the change of the spot diameter in the sub scanning direction due to image height can be minimized. Thereby, there is achieved a scanning optical apparatus which is inexpensive and suitable for highly accurate printing.

[0069]

Also, Embodiment 3 is a multibeam scanning optical apparatus using a plurality of beams of light to scan the surface to be scanned at a time and therefore, the curve of the scanning line provides pitch irregularity on the image and this is not good.

[0070]

So, in Embodiment 3, the radius of curvature in the sub scanning direction is continuously varied in the effective portion of the lens by image height, whereby the curve of the scanning line on the surface to be scanned can be eliminated as shown in Figure 12, and thus, there is achieved a scanning optical apparatus (multibeam scanning optical apparatus) of high image quality free of pitch irregularity.

[0071]

(A) and (B) of Figure 13 are cross-sectional views of the essential portions of Embodiment 4 of the present invention in the main scanning direction and the sub scanning direction, respectively. In these views, the same element as the elements shown in Figure 3 are given the same reference numerals.

[0072]

In Figure 13, reference numeral 46 designates an fθ lens (an imaging optical system) comprising a lens having the fθ characteristic as a third optical element, and this fθ lens 46 is disposed more toward the light deflector 5 than the intermediate portion between the light deflector 5 and the photosensitive drum surface 8 as the surface to be scanned.

[0073]

In Embodiment 4, the opposite lens surfaces of the fθ lens 46 both have their curvatures in the sub scanning direction continuously varied from the on-axis fθ lens 46 both have their curvatures in the sub scanning direction continuously varied from the on-axis toward the off-axis. Thereby, in Embodiment 4, the change of F number in the sub scanning direction due to the image height of the beam of light incident on the surface to be scanned, i.e., the change of the spot diameter, is minimized. Also, the sign of the

curvature of at least one (the first surface) R1 of the opposite lens surfaces of the fθ lens 46 in the sub scanning direction is reversed from the on-axis toward the off-axis. Further, the curvatures of the opposite lens surfaces of the fθ lens in the sub scanning direction are varied from the on-axis toward the off-axis so as to become asymmetrical with respect to the optical axis. The fθ lens 46 causes a plurality of beams of light based on image information deflected and reflected by the light deflector 5 to be imaged on the photosensitive drum surface 8 and corrects the plane inclination of the deflecting surface of the light deflector 5.

[0074]

In Embodiment 4, the fθ lens 46 may be made by plastic molding or may be made by glass molding.

[0075]

In Embodiment 4, two independently modulated divergent beams of light emitted from a semiconductor laser 11 are converted into convergent beams of light by the collimator lens 2, and these beams of light (the quantity of light) are limited by the aperture stop 3 and enter the cylindrical lens 4. The beams of light having entered the cylindrical lens 4, in the main scanning section, emerge therefrom intactly in that

state. Also, in the sub scanning section, they converge and are imaged as substantially linear images (linear images long in the main scanning direction) on the deflecting surface 5a of the light deflector 5. The two beams of light deflected and reflected by the deflecting surface 5a of the light deflector 5 from two spots on the photosensitive drum surface 8 through the fθ lens 46 having different refractive powers in the main scanning direction and the sub scanning direction, and scan the photosensitive drum surface 8 in the direction of arrow B by the light deflector 5 being rotated in the direction of arrow A. Thereby, image recording is effected.

[0076]

In Embodiment 4, the lens shape of the fθ lens 46, in the main scanning direction, is made into an aspherical surface shape capable of being represented by a function up to the 10th order in the main scanning direction and in the sub scanning direction, is comprised of a spherical surface continuously varying in the image height direction. That lens shape is such that the generating-line direction corresponding to the main scanning direction is indicated by the aforementioned expression (c) and the meridian-line direction corresponding to the sub scanning direction

(the direction orthogonal to the main scanning direction containing the optical axis of the fθ lens) can be represented by

[0077]

[Numerical Formula 7]

$$S=\frac{Z^2/r'}{1+(1-(Z/r')^2)^{1/2}}, \quad \cdots (f)$$

(where $r' = r(1+D_2Y^2+D_4Y^4+D_6Y^6+D_8Y^8+D_{10}Y^{10})$.

[0078]

Generally, in a multibeam scanning optical apparatus, to make pitch irregularity visually inconspicuous, it is desirable that the pitch irregularity due to the curve of the scanning line be 1/10 of the beam pitch in the sub scanning direction or less. For example, in the case of a scanning optical apparatus in which the resolution in the sub scanning direction is 600 dpi, the beam pitch in the sub scanning direction is 42 μm and therefore, allowable pitch irregularity is about 4 μm or less.

[0079]

So, in Embodiment 4, when the maximum value and the minimum value of the F number of the beam of light incident on the surface to be scanned in the sub scanning direction are Fmax and Fmin, respectively, the

curvatures of the opposite lens surfaces of the fθ lens 46b in the sub scanning direction are continuously varied from the on-axis toward the off-axis so as to satisfy the condition that

$$Fmin/Fmax \geq 0.9, \quad \ldots (2)$$

whereby the curve of the scanning line can be eliminated to thereby achieve a multibeam scanning optical apparatus which suffers little from pitch irregularity and is high in image quality and compact.

[0080]

If the above-mentioned condition is departed from, pitch irregularity will become visually conspicuous due to the curve of the scanning line and this will pose a problem in practice.

[0081]

Table 4 below shows the optical arrangement in Embodiment 4 and the aspherical surface coefficients of the fθ lens 46.

[0082]

[Table 4]

Table 4

Design Data			shape of fθ lens		
				1st surface	2nd surface
wavelength used	λ(nm)	780	R	6.7814E+01	1.6154E+02
refractive index of fθ lens	n	1.519	K	−1.6787E+01	−1.0814E+02
angle of incidence on polygon	θi	−90	B4	−9.8604E−07	−2.2909E−06
maximum angle of emergence from polygon	θmax	45	B6	1.5479E−11	7.1426E−10
polygon − fθ lens	e	36	B8	8.7055E−14	−3.2030E−13
center thickness of fθ lens	d	11	B10	−4.7942E−18	7.9836E−17
fθ lens − surface to be scanned	Sk	110.5	r	−2.8363E+01	−1.1966E+01
maximum effective diameter of fθ lens	Ymax	42	D2S	5.4992E−05	4.4462E−05
focal length of fθ lens	ft	213.7	D4S	−2.2581E−08	−2.7866E−08
degree of convergence of collimator polygon −natural converging point	fc	317.3	D6S	9.5892E−12	2.5295E−11
			D8S	−1.9648E−15	−1.0163E−14
polygon	circumscribed circle ϕ20.4 surface		D10S	2.7992E−19	1.9816E−18
			D2E	4.3102E−05	3.9194E−05
			D4E	1.7579E−08	−1.2704E−08
			D6E	−3.6419E−11	1.1605E−11
			D8E	2.1285E−14	−3.3827E−15
			D10E	−4.6427E−18	8.2100E−20

Figure 16 is an illustration showing a change of F number in the sub scanning direction on the surface to be scanned in Embodiment 4. In Embodiment 4, the curvatures of the fθ lens 46 in the sub scanning direction are continuously varied on the opposite lens surfaces from the on-axis toward the off-axis as shown in Figure 19 to thereby suppress the rate of change of F number due to image height so as to be

$$Fmin/Fmax = 64.52/66.31 = 0.973,$$

i.e., 0.9 or greater.

[0083]

Figure 22 is an illustration showing the curve of the scanning line when the multibeam scanning optical apparatus of Embodiment 4 is used at resolution 600 dpi (scanning line interval 42.3 μm). By suppressing the change of F number due to image height as described above, the curve of the scanning line can be brought to a level of the order of 0.2 μm (pitch irregularity being of the order of 0.4 μm) which is quite free of a practical problem.

[0084]

Thus, in Embodiment 4, as described above, conditional expression (2) is satisfied and yet the curvatures of the fθ lens 46 in the sub scanning direction (the meridian-line direction) are

continuously varied from the on-axis toward the off-axis to thereby suppress the change of F number in the sub scanning direction due to image height, i.e., the change of the spot diameter, to below a predetermined amount (within the allowable value of the apparatus) and eliminate the pitch irregularity due to the curve of the scanning line which poses a problem in the multibeam scanning optical apparatus. Also, in Embodiment 4, the third optical element (fθ lens) 46 is comprised of a single lens and therefore, there can be achieved a compact and low-cost multibeam scanning optical apparatus.

[0085]

(A) and (B) of Figure 14 are cross-sectional views of the essential portions of Embodiment 5 of the present invention in the main scanning direction and the sub scanning direction, respectively. In these views, the same elements as the elements shown in Figure 3 are given the same reference numerals.

[0086]

The differences of Embodiment 5 from the aforedescribed Embodiment 4 are that in order to make curvature of image field in the main scanning direction small so as to be capable of coping with further highly accurate printing, the curvatures of the opposite lens

surfaces of an fθ lens 56 in the generating-line direction are set so as to be asymmetrical with the optical axis, and that the number of the polygon surfaces of the polygon mirror 15 is changed from four to six to thereby cope with high-speed printing. In the other points, the construction and optical action of Embodiment 5 are substantially similar to those of Embodiment 4, whereby a similar effect is obtained.

[0087]

Table 5 below shows the optical arrangement in Embodiment 5 and the aspherical surface coefficients of the fθ lens 56.

[0088]

[Table 5]

Table 5

Design Data				shape of fθ lens	
				1st surface	2nd surface
wavelength used	λ(nm)	780	R	7.6014E+01	1.8577E+02
refractive index of fθ lens	n	1.524	K	-1.4188E+01	-9.3624E+01
angle of incidence on polygon	θi	-60	B4S	-8.8268E-07	-1.6683E-06
maximum angle of emergence from polygon	θmax	41.0	B6S	8.8566E-11	3.5647E-10
polygon - fθ lens	e	41.1	B8S	4.0586E-14	-1.2120E-13
center thickness of fθ lens	d	10.4	B10S	-5.2861E-19	3.5062E-17
fθ lens - surface to be scanned	Sk	122.5	B4E	-8.8268E-07	-1.6683E-06
maximum effective diameter of fθ lens	Ymax	42	B6E	5.2038E-11	3.5647E-10
focal length of fθ lens	ft	237.7	B8E	6.4399E-14	-1.2120E-13
degree of convergence of collimator polygon -natural converging point	fc	339.69	B10E	-5.1518E-18	3.5062E-17
			r	-3.0459E+01	-1.3017E+01
polygon	circumscribed circle ϕ40.6 surface		D2S	-3.2380E-05	-1.4111E-06
			D4S	7.6080E-08	1.0715E-09
			D6S	-3.4870E-11	1.7648E-11
			D8S	5.0570E-15	-8.2750E-15
			D10S	0.0000E+00	1.0082E-18
			D2E	-3.5200E-05	-1.4111E-06
			D4E	8.0516E-08	1.0715E-09
			D6E	-3.8015E-11	1.7648E-11
			D8E	6.0665E-15	-8.2750E-15
			D10E	-1.1908E-19	1.0082E-18

Figure 17 is an illustration showing a change of F number in the sub scanning direction on the surface to be scanned in Embodiment 5. In Embodiment 5, the curvatures of the fθ lens 56 in the sub scanning direction are continuously varied on the opposite lens surfaces from the on-axis toward the off-axis as shown in Figure 20, to thereby suppress the rate of change of F number due to image height so as to be

Fmin/Fmax = 49.75/53.08 = 0.937,

i.e., 0.9 or greater.

[0089]

Figure 23 is an illustration showing the curve of the scanning line when the multibeam scanning optical apparatus of Embodiment 5 is used at resolution 600 dpi (the scanning line interval 42.3 μ). By suppressing the change of F number due to image height as described above, the curve of the scanning line can be brought to a level of the order of 1.2 μ (the pitch irregularity being of the order of 2.4 μm) quite free of a practical problem.

[0090]

Thus, again in Embodiment 5, as in Embodiment 4, conditional expression (2) is satisfied and yet the curvatures of the opposite lens surfaces of the fθ lens 56 in the sub scanning direction (the meridian-line

direction) are continuously varied from the on-axis toward the off-axis to thereby suppress the change of F number in the sub scanning direction due to image height, i.e., the change of the spot diameter, to below a predetermined amount, and eliminate the pitch irregularity due to the curve of the scanning line which poses a problem in the multibeam scanning optical apparatus. Also, in Embodiment 5, the curvatures of the opposite lens surfaces of the fθ lens (the third optical element) 56 in the generating-line direction are set so as to be asymmetrical with respect to the optical axis to thereby suppress the curvature of image field in the main scanning direction and achieve a multibeam scanning optical apparatus suitable for further highly accurate printing.

[0091]

(A) and (B) of Figure 15 are cross-sectional views of the essential portions of Embodiment 6 of the present invention in the main scanning direction and the sub scanning direction, respectively. In these views, the same element as the elements shown in Figure 3 are given the same reference numerals.

[0092]

The differences of Embodiment 6 from the aforedescribed Embodiment 4 are that an fθ lens (the

third optical element) 76 is comprised of two lenses and the pitch irregularity due to the curve of the scanning line is reduced at higher accuracy, that the beam of light from a semiconductor laser 11 having a plurality of light emitting portions capable of being independently modulated is converted into a substantially parallel beam of light by the collimator lens 2, and that the number of the polygon surfaces of the polygon mirror 15 is changed from four to six to thereby cope with high-speed printing. In the other points, the construction and optical action of Embodiment 6 are substantially similar to those of the aforedescribed Embodiment 4, whereby a similar effect is obtained.

[0093]

That is, in Figure 15, reference numeral 76 designates an fθ lens as a third optical element, which comprises two lenses, i.e., a spherical lens (glass spherical lens) 76a as a first fθ lens formed of a glass material, and a toric lens (aspherical plastic toric lens) 76b as a second fθ lens of an aspherical surface shape formed of a plastic material. The glass spherical lens 76a is disposed more toward the light deflector 15 than the intermediate portion between the light deflector 15 and the photosensitive drum surface

8 and has the function of correcting chiefly the fθ characteristic. The aspherical plastic toric lens 76b effects chiefly the correction of curvature of image field and the correction of lateral magnification in the sub scanning direction.

[0094]

In Embodiment 6, the curvatures, in the meridianline direction (the sub scanning direction), of the opposite lens surfaces of the aspherical plastic toric lens 76b bearing almost all of the refractive power in the sub scanning direction are continuously varied from the on-axis toward the off-axis to thereby suppress the change of F number in the sub scanning direction on the surface to be scanned, i.e., the change of the spot diameter.

[0095]

Table 6 below shows the optical arrangement in Embodiment 6 and the aspherical surface coefficients of the fθ lens (spherical lens 76a and toric lens 76b) 76.

[0096]

[Table 6]

Table 6

Design Data				shape of fθ lens	
				1st surface	2nd surface
wavelength used	λ(nm)	780	R	∞	−1.2042E+02
refractive index of 1st fθ lens	n1	1.786	r	∞	−1.2042E+02
refractive index of 2nd fθ lens	n2	1.572		shape of 2nd fθ lens	
angle of incidence on polygon	θi	65		1st surface	2nd surface
maximum angle of emergence from polygon	θmax	45	R	−8.7734E+02	−3.4387E+02
polygon − 1st fθ lens	e1	25.28	K	0.0000E+00	0.0000E+00
center thickness of 1st fθ lens	d1	14.00	B4	−1.5203E−08	6.2830E−08
focal length of 1st to 2nd fθ lens	e2	17.60	B6	−1.2062E−11	−1.5527E−11
center thickness of 2nd fθ lens	d2	5.10	r	−1.2218E+01	−9.9688E+00
fθ lens − surface to be scanned	Sk	116.13	D2S	−4.2145E−07	4.2877E−07
maximum effective diameter of fθ lens	Ymax	50	D4S	1.3072E−10	−7.9350E−10
focal length of fθ lens	ft	136	D6S	6.7762E−13	7.0965E−13
polygon	circumscribed circle ϕ40.6 surface		D2E	2.2156E−07	1.2975E−07
			D4E	2.2156E−07	1.2975E−07
			D6E	4.9138E−13	4.3863E−13

Figure 18 is an illustration showing a change of F number in the sub scanning direction on the surface to be scanned in Embodiment 6. In Embodiment 6, the curvatures of the toric lens 76b in the sub scanning direction are continuously varied on the opposite lens surface thereof from the on-axis toward the off-axis as shown in Figure 21 to thereby suppress the rate of change of F number due to image height so as to be

$$Fmin/Fmax = 72.67/73.75 = 0.985,$$

i.e., 0.9 or greater.

[0097]

Figure 24 is an illustration showing the curve of the scanning line when the multibeam scanning optical apparatus of Embodiment 6 is used at resolution 600 dpi (scanning line interval 42.3 μm). By suppressing the change of F number due to image height, the curve of the scanning line can be brought to a level of the order of 0.1 μm (pitch irregularity being of the order of 0.2 μm) free of a practical problem.

[0098]

Thus, again in Embodiment 6, as in the aforedescribed Embodiment 4, conditional expression (2) is satisfied and yet the curvatures of the opposite lens surfaces of the toric lens 76b constituting the fθ lens 76 in the sub scanning direction (the meridian-

line direction) are continuously varied from the on-axis toward the off-axis to thereby suppress the change of F number in the sub scanning direction due to height, i.e., the change of the spot diameter, to below a predetermined amount and eliminate the pitch irregularity due to the curve of the scanning line which poses a problem in the multibeam scanning optical apparatus. Also, in Embodiment 6, by the fθ lens (the third optical element) 76 being comprised of two lenses, the curve of the scanning line can be corrected more highly accurately, and there is achieved a multibeam scanning optical apparatus suitable for further highly accurate printing.

[0099]

The sign of the curvature of at least one of the two lenses constituting the third optical element in the sub scanning direction may be reversed from the on-axis toward the off-axis, and the curvatures of at least two lens surfaces of the two lenses in the sub scanning direction may be varied asymmetrically with respect to the optical axis from the on-axis toward the off-axis. Thereby, there can be achieved a multibeam scanning optical apparatus more suitable for highly accurate printing.

[0100]

Lastly, for the comparison with the scanning optical apparatus of the present invention, description will be made of the manner in which multibeam scanning was effected by the prior-art single beam scanning optical apparatus shown in (A) and (B) of Figure 26.

[0101]

(A) and (B) of Figure 28 are cross-sectional views of the essential portions in the main scanning direction and the sub scanning direction, respectively, when multibeam scanning was effected by the use of the prior-art single beam scanning optical apparatus shown in (A) and (B) of Figure 28, and show the changes of the angular magnification in the sub scanning direction and the spot diameter (F number) in the sub scanning direction on the surface to be scanned, due to image height. Table 7 below shows the optical arrangement shown in (A) and (B) of Figure 28 and the aspherical surface coefficients of an fθ lens 86.

[0102]

[Table 7]

Table 7

Design Data				shape of fθ lens	
				1st surface	2nd surface
wavelength used	λ(nm)	780	R	6.7814E+01	1.6154E+02
refractive index of fθ lens	n	1.519	K	−1.6787E+01	−1.0814E+02
angle of incidence on polygon	θi	−90	B4	−9.8604E−07	−2.2909E−06
maximum angle of emergence from polygon	θmax	45	B6	1.5479E−11	7.1426E−10
polygon − fθ lens	e	36	B8	8.7055E−14	−3.2030E−13
center thickness of fθ lens	d	11	B10	−4.7942E−18	7.9836E−17
fθ lens − surface to be scanned	Sk	110.5	r	−2.8531E+01	−1.1991E+01
maximum effective diameter of fθ lens	Ymax	42	D2S	0.0000E+00	2.1635E−05
focal length of fθ lens	ft	213.7	D4S	0.0000E+00	−3.6548E−08
degree of convergence of collimator polygon −natural converging point	fc	317.3	D6S	0.0000E+00	2.7926E−11
			D8S	0.0000E+00	−1.1184E−14
polygon	circumscribed circle ϕ20.4 surface		D10S	0.0000E+00	1.7618E−18
			D2E	0.0000E+00	2.2817E−05
			D4E	0.0000E+00	−3.8012E−08
			D6E	0.0000E+00	2.9368E−11
			D8E	0.0000E+00	−1.2060E−14
			D10E	0.0000E+00	1.9700E−18

In Figure 28, two in dependently modulated divergent beams of light emitted from light source means 81 are converted into convergent beams of light by a collimator lens 82, and these beams of light (the quantity of light) are limited by a stop 83 and enter a cylindrical lens 84 having predetermined refractive power. The beams of light having entered the cylindrical lens 84, in the main scanning plane, intactly emerge in that state. Also, in the sub scanning section, they converge and are imaged as substantially linear images on the deflecting surface (reflecting surface) 85a of a light deflector 85 comprising a rotatable polygon mirror. The two beams of light deflected and reflected by the deflecting surface 85a of the light deflector 85 are directed onto a photosensitive drum surface as a surface 88 to be scanned through an imaging optical system (fθ lens) 86 having the fθ characteristic, and the light deflector 85 is rotated in the direction of arrow A, whereby the photosensitive drum surface 88 is light-scanned to thereby effect the recording of image information.

[0103]

Usually, in a plane inclination correcting optical system, as previously described, it is necessary to bring the deflecting surface of the light deflector and

the surface to be scanned into optically conjugate relationship (imaging relationship) with each other in order to optically correct the plane inclination of the deflecting surface. In the comparative example shown in Figure 28, with the curvature in the sub scanning direction (meridian line curvature) of that lens surface (first surface) R1 of the fθ lens 86 which is adjacent to the light deflector 85 being constant, the curvature in the sub scanning direction (meridian line curvature) of that lens surface (second surface) R2 of the fθ lens 86 which is adjacent to the surface to be scanned is continuously varied from the on-axis toward the off-axis to thereby bring about conjugate relationship at any image height.

[0104]

However, the fθ lens 86 in the above-described comparative example is constant in the meridian line curvature of one surface (surface R1) thereof as shown in Figure 30 and therefore, as shown in Figure 29, depending on the bus line shape thereof, F number (F No) becomes irregular due to image height. That is, on the axis (the on-axis beam), the F number in the sub scanning direction on the surface to be scanned is great as shown in (1) in (B) of Figure 28 and therefore, the angular magnification in the sub

scanning direction is small, and off the axis (the off-axis beam), the F number in the sub scanning direction is small as shown in (2) in (B) of Figure 28 and therefore, the angular magnification is great (there is a converse case depending on the main scanning plane shape).

[0105]

Generally, between the angular magnification γ and the lateral magnification β, the relation that

$\beta\gamma = -1$

is established and therefore, in the above-described comparative example, the lateral magnification becomes great on the axis and the lateral magnification becomes small off the axis. Therefore, due to image height, irregularity is created in the lateral magnification in the sub scanning direction, and in an optical system like a multibeam scanning optical apparatus which uses a plurality of laser beams off the optical axis to scan, the scanning line makes a curve on the surface to be scanned.

[0106]

Figure 31 is an illustration showing the curve of the scanning line when the multibeam scanning optical apparatus of the comparative example is used at resolution 600 dpi (scanning line interval 42.3 μm).

In Figure 31, the scanning line in the marginal portion is curved by 2.4 μm with respect to the central portion, and this leads to the problem that pitch irregularity of 4.8 μm will result and deteriorate the quality of image.

[0107]

[Effect of the Invention]

The above-noted problem does not arise in the scanning optical apparatus of the present invention, and according to a first invention, there can be achieved a compact scanning optical apparatus suitable for highly accurate printing in which when as previously described, a beam of light from a light source converted by a collimator lens or the like is to be imaged on a surface to be scanned by an fθ lens through a light deflector, curvature of image field, distortion, etc. are well corrected by optimizing the lens shape of the fθ lens and the non-uniformity of the lateral magnification in the sub scanning direction between the light deflector and the surface to be scanned can be eliminated to thereby suppress the change of F number in the sub scanning direction due to image height, i.e., the change of the spot diameter.

[0108]

Also, according to a second invention, there can

be achieved a multibeam scanning optical apparatus in which when as previously described, a plurality of beams of light from a light source converted by a collimator lens or the like are to be imaged on a surface to be scanned by an fθ lens through a light deflector, curvature of image field, distortion, etc. are well corrected by optimizing the lens shape of the fθ lens and the non-uniformity of the lateral magnification in the sub scanning direction between the light deflector and the surface to be scanned can be eliminated to thereby suppress the change of F number in the sub scanning direction due to image height, i.e., the change of the spot diameter, and reduce the pitch irregularity due to the curve of the scanning line.

[0109]

Further, there can be achieved a multibeam scanning optical apparatus in which the curvature of the fθ lens in the sub scanning direction is determined so as to satisfy the aforementioned conditional expression (2), whereby pitch irregularity can be reduced to a visually problem-free level.

[Brief Description of the Drawings]

[Figure 1]

Cross-sectional views of the essential portions of

Embodiment 1 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[Figure 2]

Cross-sectional views of the essential portions of Embodiment 2 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[Figure 3]

Cross-sectional views of the essential portions of Embodiment 3 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[Figure 4]

An illustration showing the aspherical surface shape of an fθ lens in Embodiment 1 of the present invention.

[Figure 5]

An illustration showing the aspherical surface shape of an fθ lens in Embodiment 2 of the present invention.

[Figure 6]

An illustration showing the aspherical surface shape of an fθ lens in Embodiment 3 of the present invention.

[Figure 7]

An illustration showing the shape of the fθ lens in Embodiment 1 of the present invention in the main scanning direction.

[Figure 8]

An illustration showing the shape of the fθ lens in Embodiment 2 of the present invention in the main scanning direction.

[Figure 9]

An illustration showing the shape of the fθ lens in the main scanning direction in Embodiment 3 of the present invention.

[Figure 10]

An illustration showing the defocus characteristic of a spot diameter in the sub scanning direction on a surface to be scanned in Embodiment 1 of the present invention.

[Figure 11]

An illustration showing the defocus characteristic of the spot diameter in the sub scanning direction on a surface to be scanned in Embodiment 2 of the present invention.

[Figure 12]

An illustration showing the curve of a scanning line in Embodiment 3 of the present invention.

[Figure 13]

Cross-sectional views of the essential portions of Embodiment 4 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[Figure 14]

Cross-sectional views of the essential portions of Embodiment 5 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[Figure 15]

Cross-sectional views of the essential portions of Embodiment 6 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[Figure 16]

An illustration showing a change in F number in the sub scanning direction on a surface to be scanned relative to image height in Embodiment 4 of the present invention.

[Figure 17]

An illustration showing a change of F number in the sub scanning direction on a surface to be scanned relative to image height in Embodiment 5 of the present invention.

[Figure 18]

An illustration showing a change of F number in the sub scanning direction on a surface to be scanned relative to image height in Embodiment 6 of the present invention.

[Figure 19]

An illustration showing the curvature of an fθ lens in the meridian-line direction relative to image height in Embodiment 4 of the present invention.

[Figure 20]

An illustration showing the curvature of an fθ lens in the meridian-line direction relative to image height in Embodiment 5 of the present invention.

[Figure 21]

An illustration showing the curvature of an fθ lens in the meridian-line direction relative to image height in Embodiment 6 of the present invention.

[Figure 22]

An illustration showing the curvature of a scanning line during multibeam scanning at resolution 600 dpi (scanning line interval 42.3 μm) in Embodiment 4 of the present invention.

[Figure 23]

An illustration showing the curve of a scanning line during multibeam scanning at resolution 600 dpi

(scanning line interval 42.3 μm) in Embodiment 5 of the present invention.

[Figure 24]

An illustration showing the curve of a scanning line during multibeam scanning at resolution 600 dpi (scanning line interval 42.3 μm) in Embodiment 6 of the present invention.

[Figure 25]

A schematic view of the essential portions of the optical system of a scanning optical apparatus according to the prior art.

[Figure 26]

Cross-sectional views of the essential portions of the scanning optical apparatus according to the prior art in the main scanning direction and the sub scanning direction, respectively.

[Figure 27]

A cross-sectional view of the essential portions of a scanning optical apparatus between a deflecting element and a surface to be scanned in the main scanning direction.

[Figure 28]

Cross-sectional views of the essential portions in the main scanning direction and the sub scanning direction, respectively, when multibeam scanning was

effected by the use of the prior-art single beam scanning optical apparatus shown in Figure 26.

[Figure 29]

An illustration showing a change of F number in the sub scanning direction on a surface to be scanned relative to image height in the single beam scanning optical apparatus shown in Figure 28.

[Figure 30]

An illustration showing the curvature of an fθ lens in the meridian-line direction relative to image height in the single beam scanning optical apparatus shown in Figure 28.

[Figure 31]

An illustration showing the curve of a scanning line during multibeam scanning at resolution 600 dpi (scanning line interval 42.3 μm) in the single beam scanning optical apparatus shown in Figure 28.

[Description of Reference Numerals or Symbols]

1, 11 ... Light source means

2 ... First optical element (collimator lens)

3 ... Aperture stop

4 ... Second optical element (cylindrical lens)

5, 15 ... Deflecting elements (light deflectors)

6, 26, 36 ... Third optical elements (fθ lenses)

46, 56, 76 ... Third optical elements (fθ lenses)

76a ... Spherical lens

76b ... toric lens

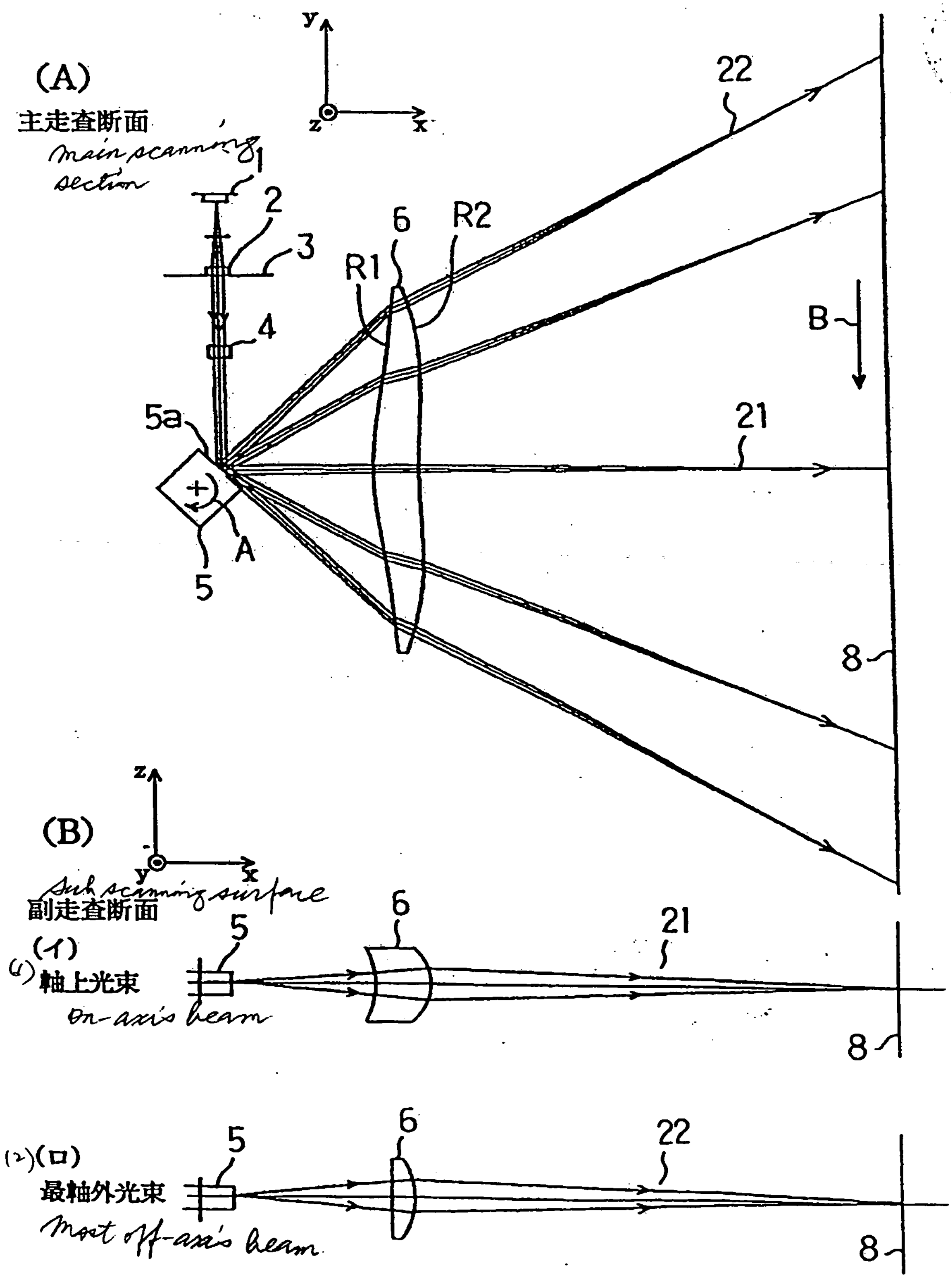
8 ... Surface to be scanned (photosensitive drum)

21 ... On-axis beam

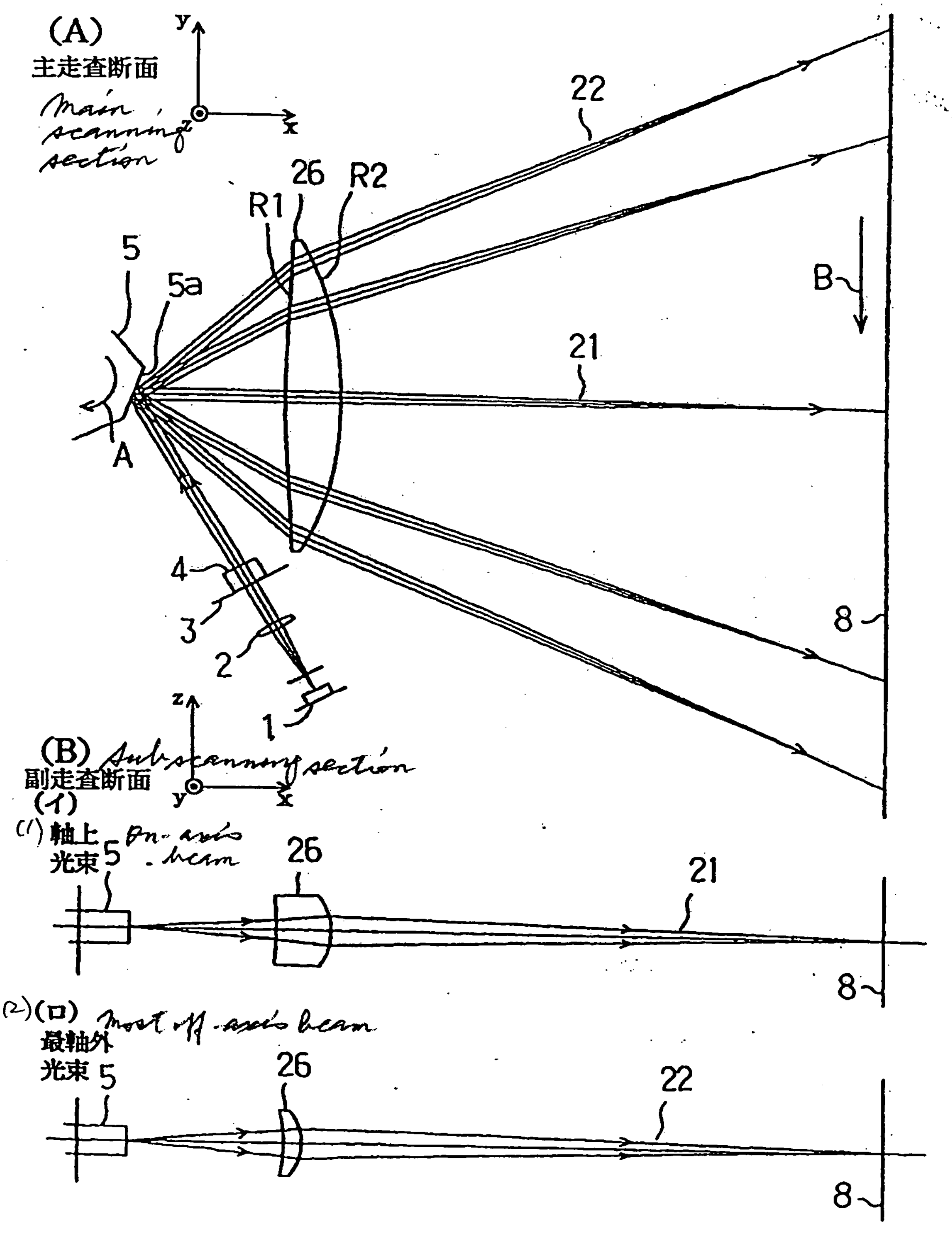
22 ... Most off-axis beam

【書類名】　図面　[Name of the Document] Drawings

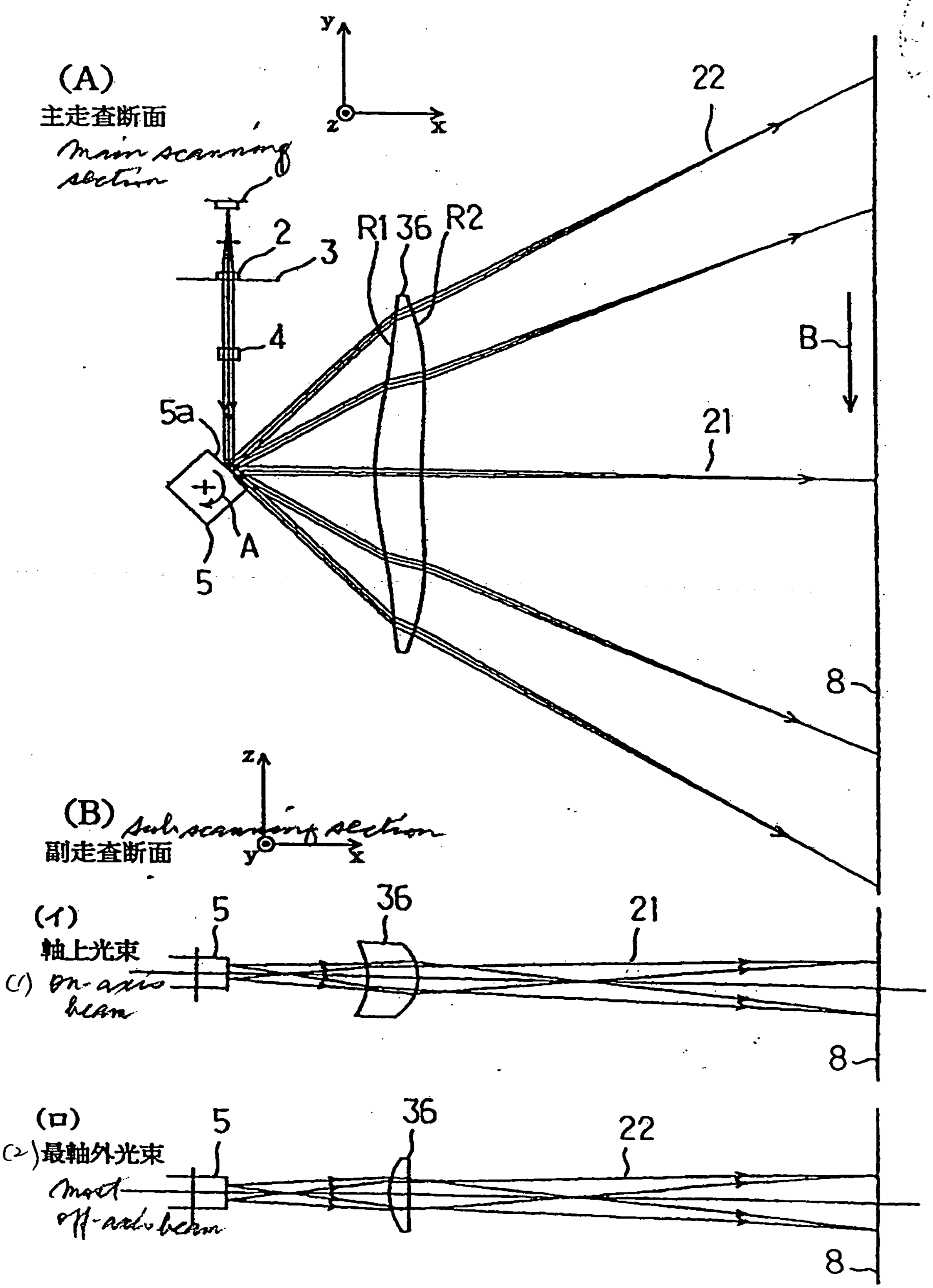
【図１】 Fig. 1



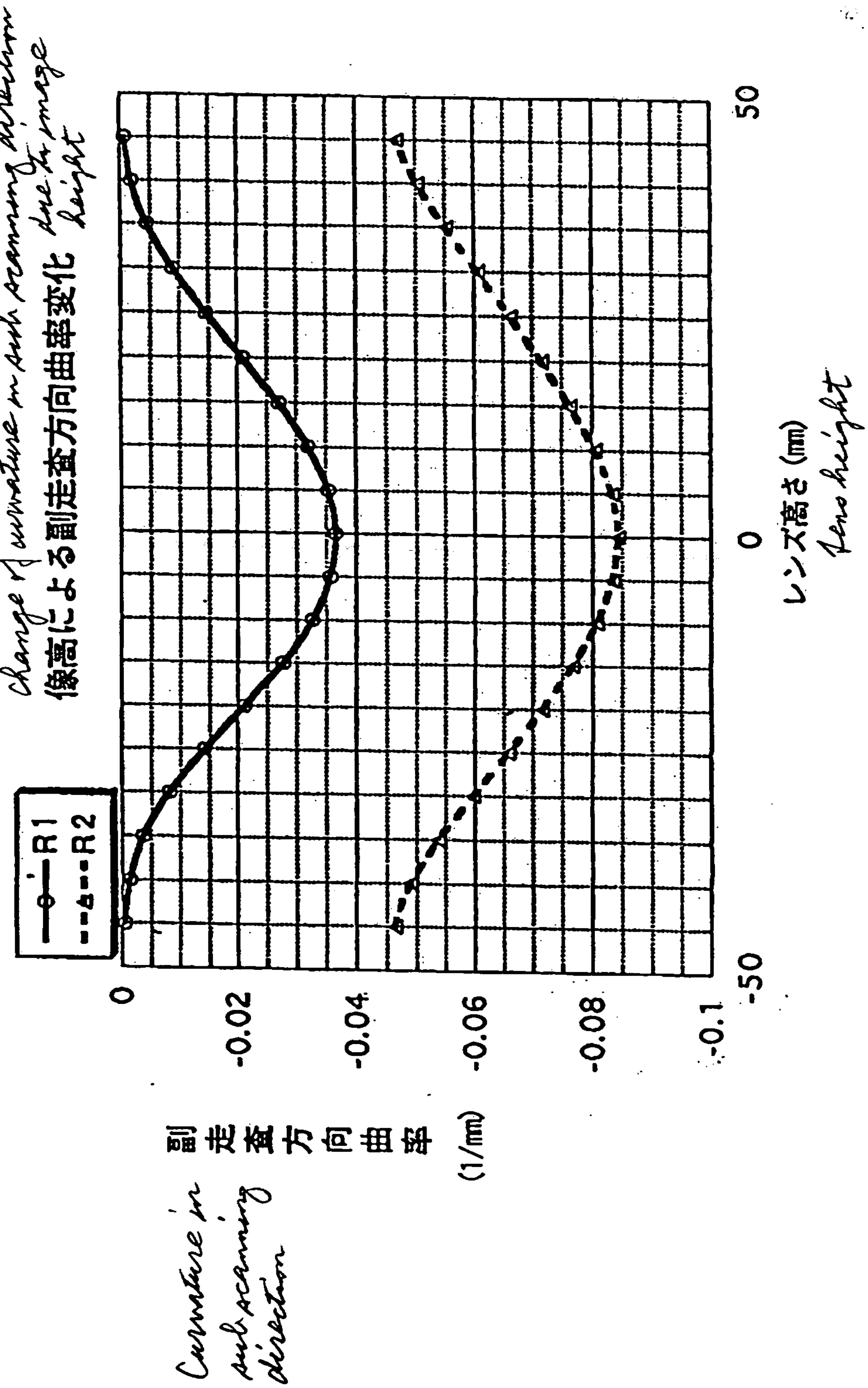
【図２】 Fig. 2


(A)
主走査断面
Main scanning section
y
z
x
22
26
R1
R2
5
5a
B
21
A
4
3
2
1
8
(B) Sub scanning section
副走査断面
z
y
x
(イ)
(1) 軸上光束 On-axis beam
5
26
21
8
(2)(ロ) Most off-axis beam
最軸外光束
5
26
22
8

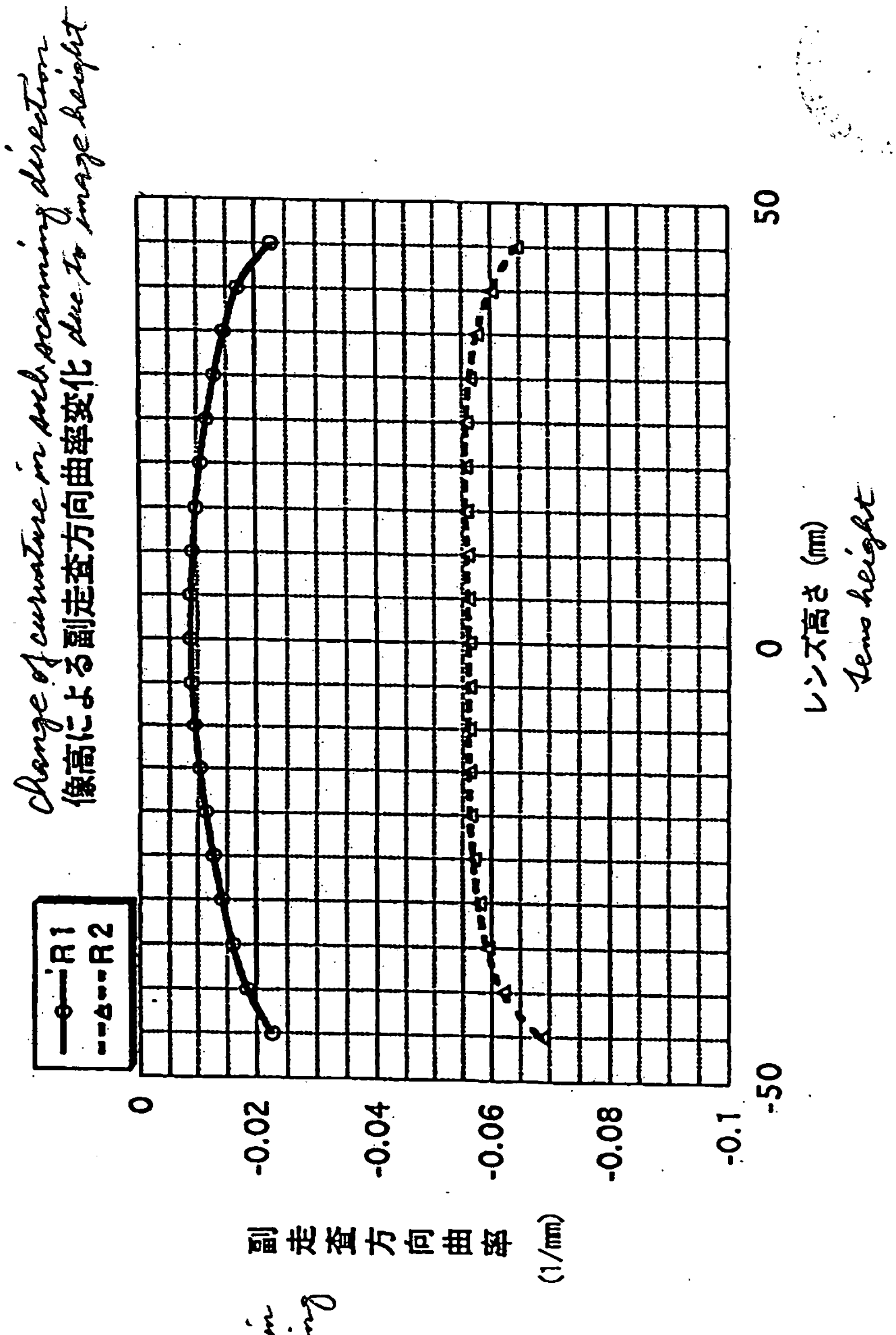
【図３】 Fig.3


(A)
主走査断面
main scanning section
y
z
x
1
2
3
4
5a
5
A
R1
36
R2
22
21
B
8
(B)
sub scanning section
副走査断面
z
y
x
(イ)
軸上光束
(1) on-axis beam
5
36
21
8
(ロ)
(2) 最軸外光束
most off-axis beam
5
36
22
8

【図４】 Fig. 4

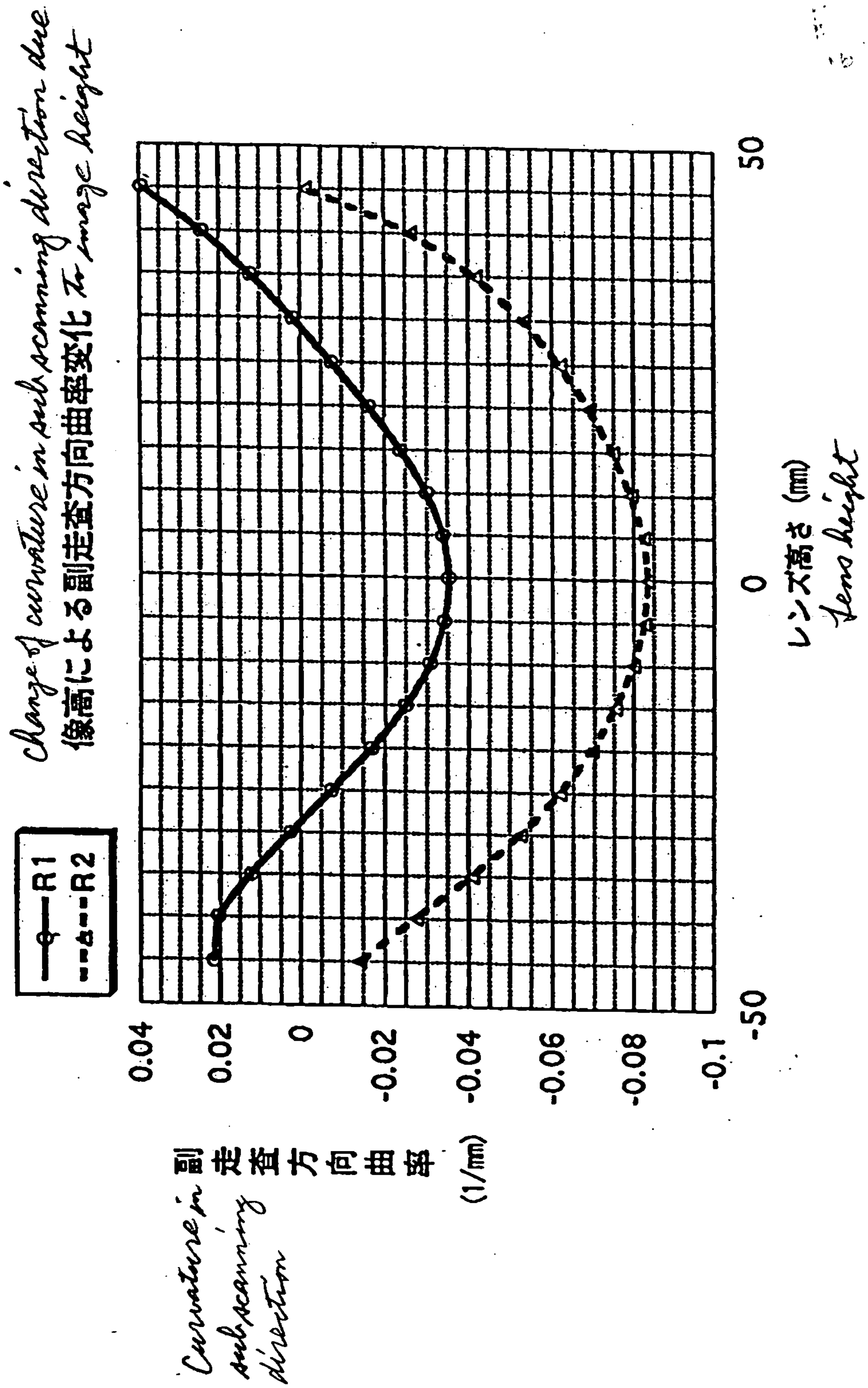

change of curvature in sub scanning direction due to image height
像高による副走査方向曲率変化
R1
R2
50
0
-50
レンズ高さ (mm)
Lens height
0
-0.02
-0.04
-0.06
-0.08
-0.1
副走査方向曲率 (1/mm)
Curvature in sub scanning direction

【図５】 Fig 5



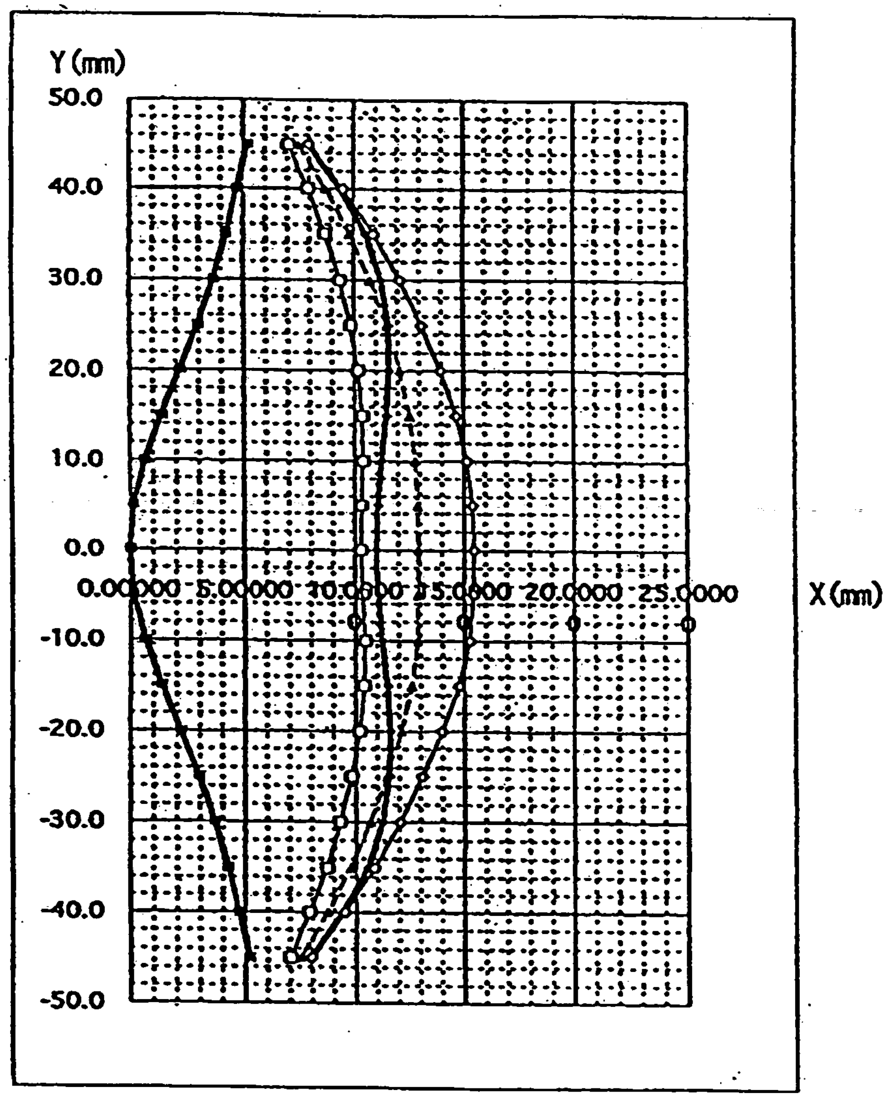
Curvature in sub scanning direction

【図６】 Fig. 6

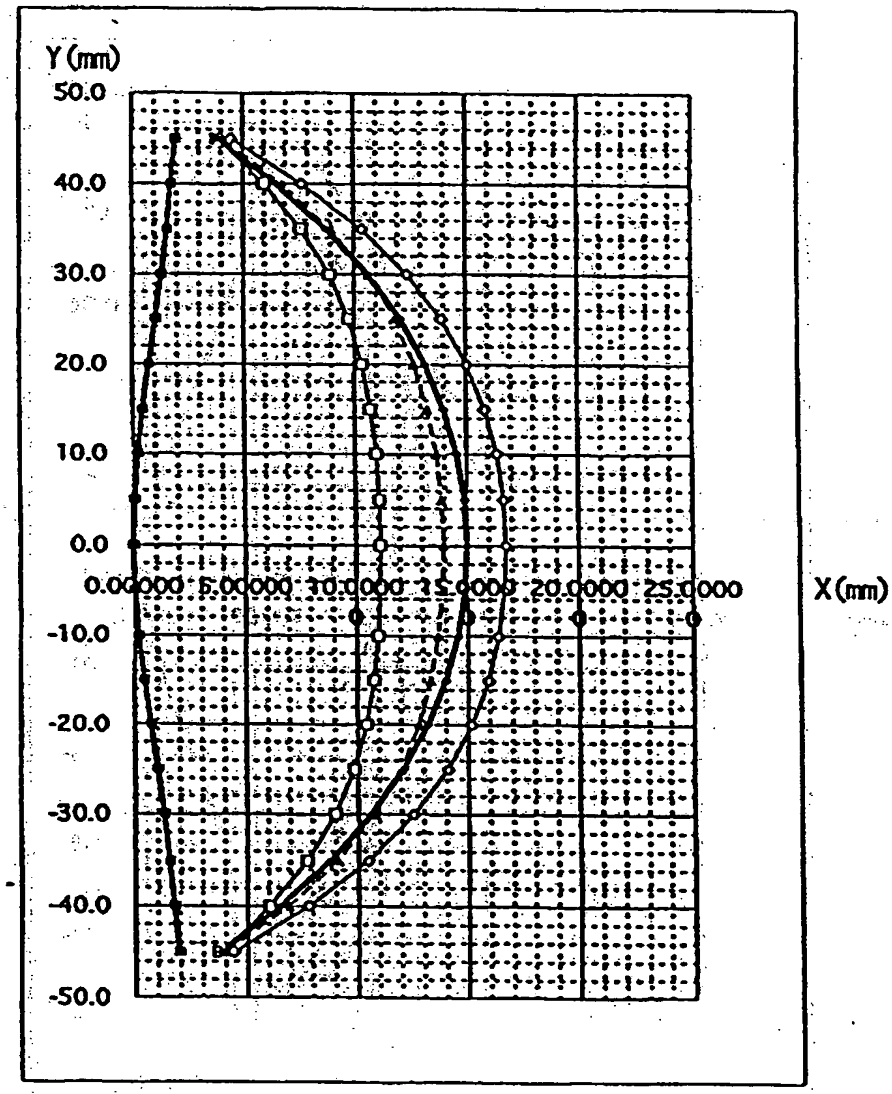


Change of curvature in sub scanning direction due to image height
像高による副走査方向曲率変化
R1
R2
50
0
-50
レンズ高さ (mm)
Lens height
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
副走査方向曲率 (1/mm)
Curvature in sub scanning direction

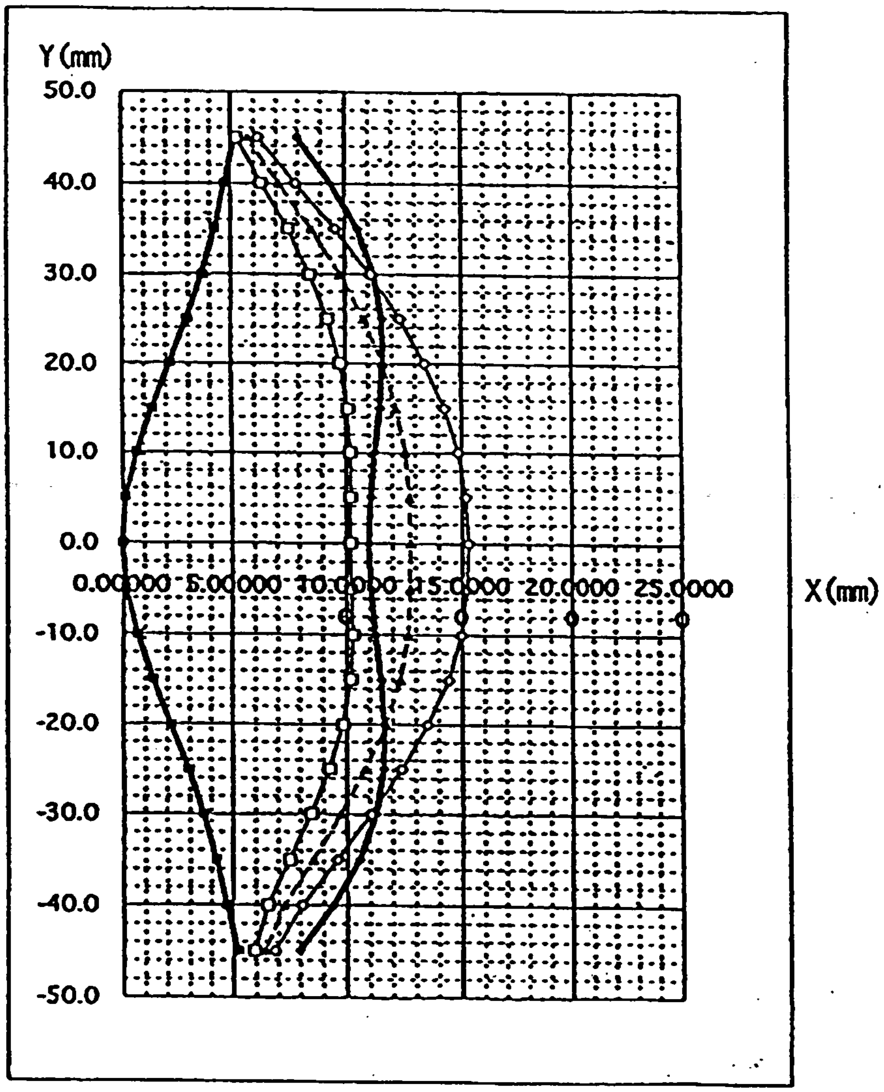
【図７】 Fig. 7


Y (mm)
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
0.00000
5.00000
10.0000
15.0000
20.0000
25.0000
X (mm)

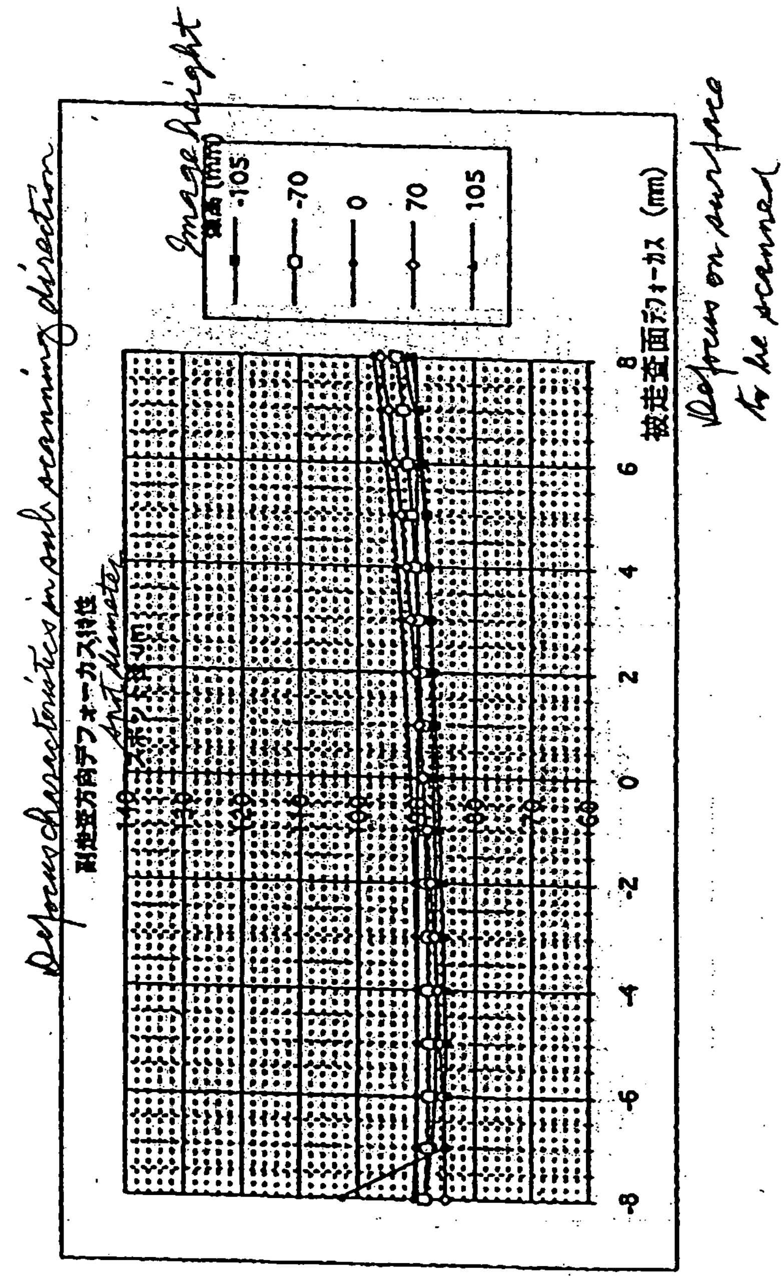
【図８】 Fig. 8


Y (mm)
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
0.00000
5.00000
10.0000
15.0000
20.0000
25.0000
X (mm)
A
B

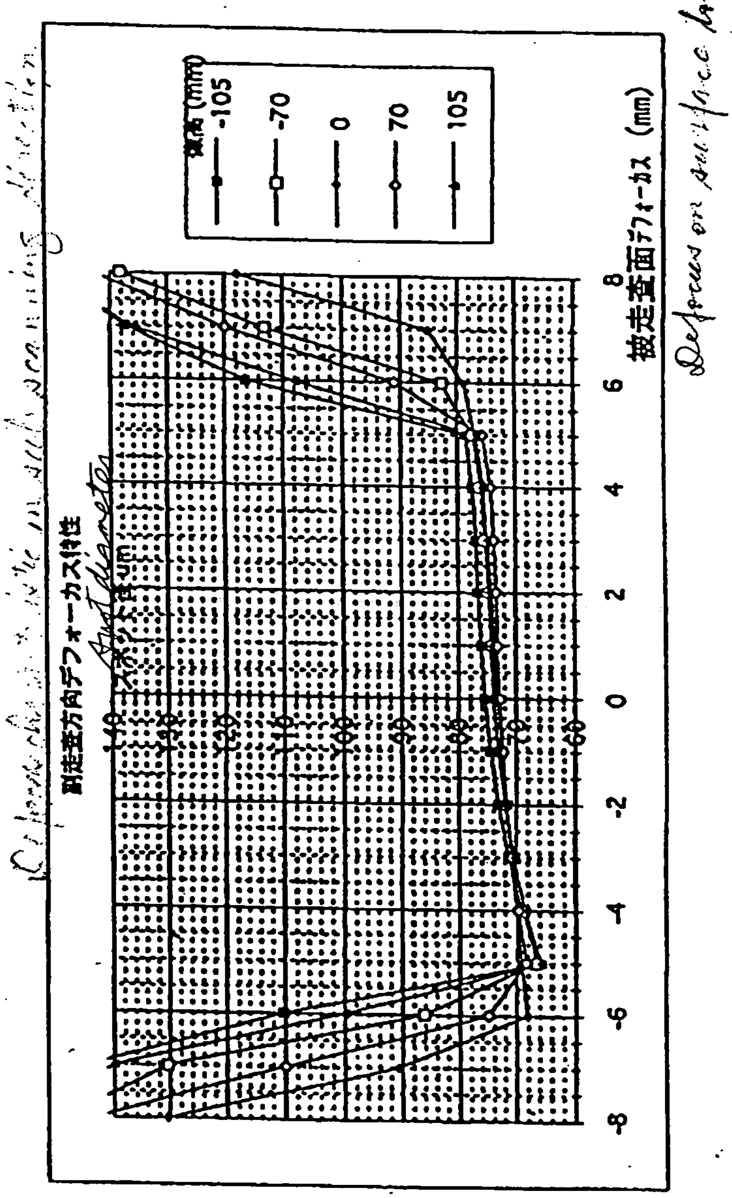
【図９】 Fig. 9


Y (mm)
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
0.00000
5.00000
10.0000
15.0000
20.0000
25.0000
X (mm)

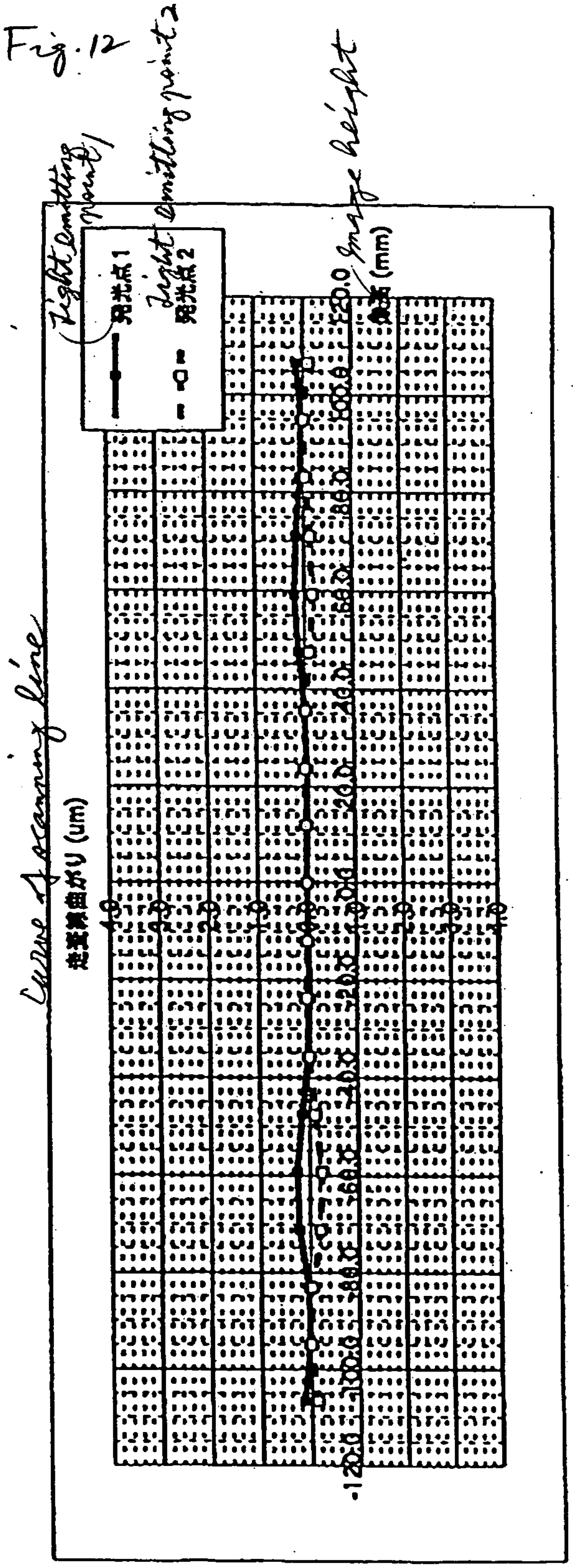
【図１０】 Fig. 10


Defocus characteristics in sub scanning direction
副走査方向デフォーカス特性
スポット径(μm)
Spot diameter
140
130
120
110
100
90
80
70
60
-8
-6
-4
-2
0
2
4
6
8
被走査面デフォーカス (mm)
Defocus on surface to be scanned
Image height
像高 (mm)
-105
-70
0
70
105

【図１１】 Fig. 11

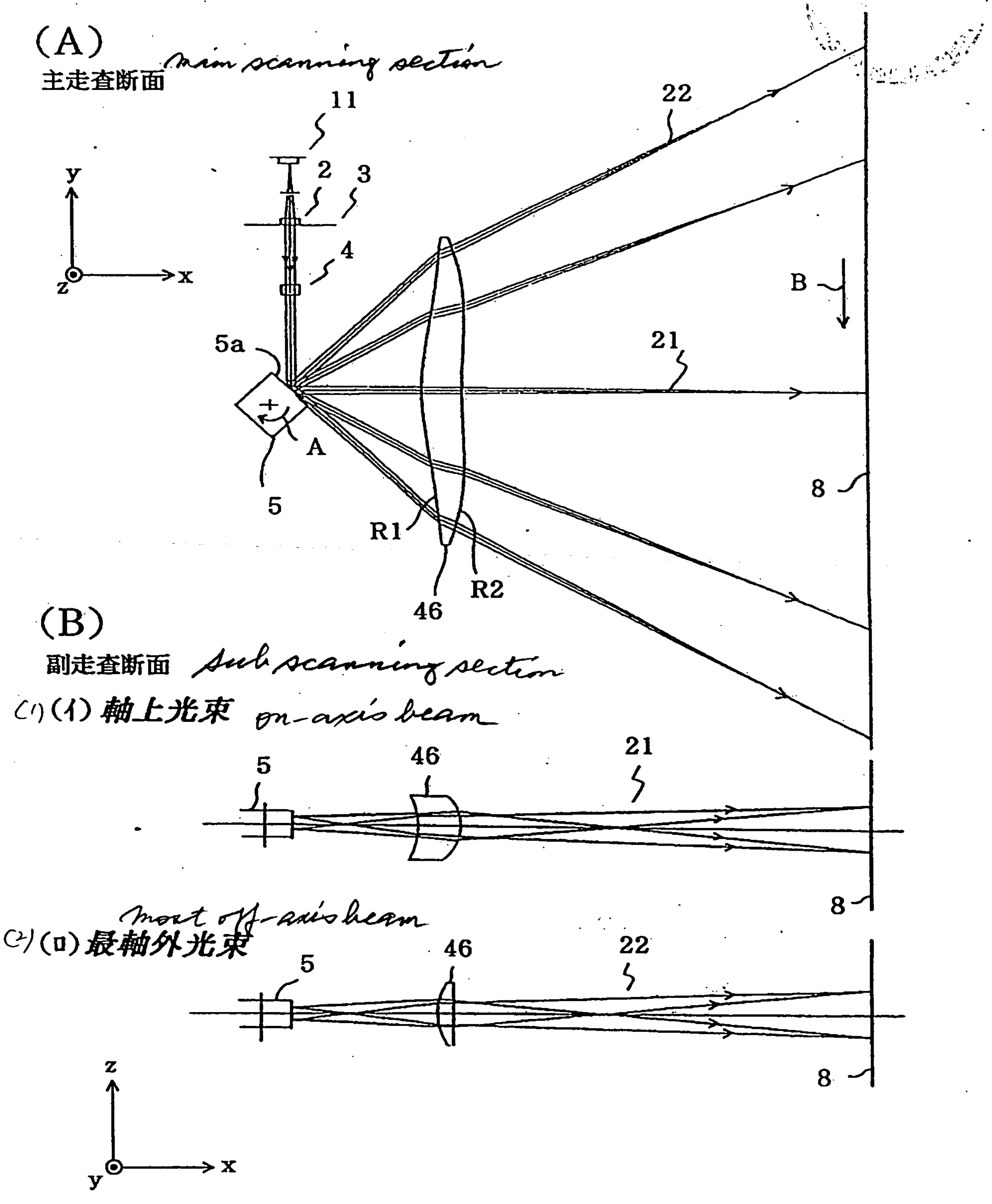

副走査方向デフォーカス特性
スポット径 um
Spot diameter
像高 (mm)
-105
-70
0
70
105
被走査面デフォーカス (mm)
Defocus on surface to be scanned

【図１２】 Fig. 12

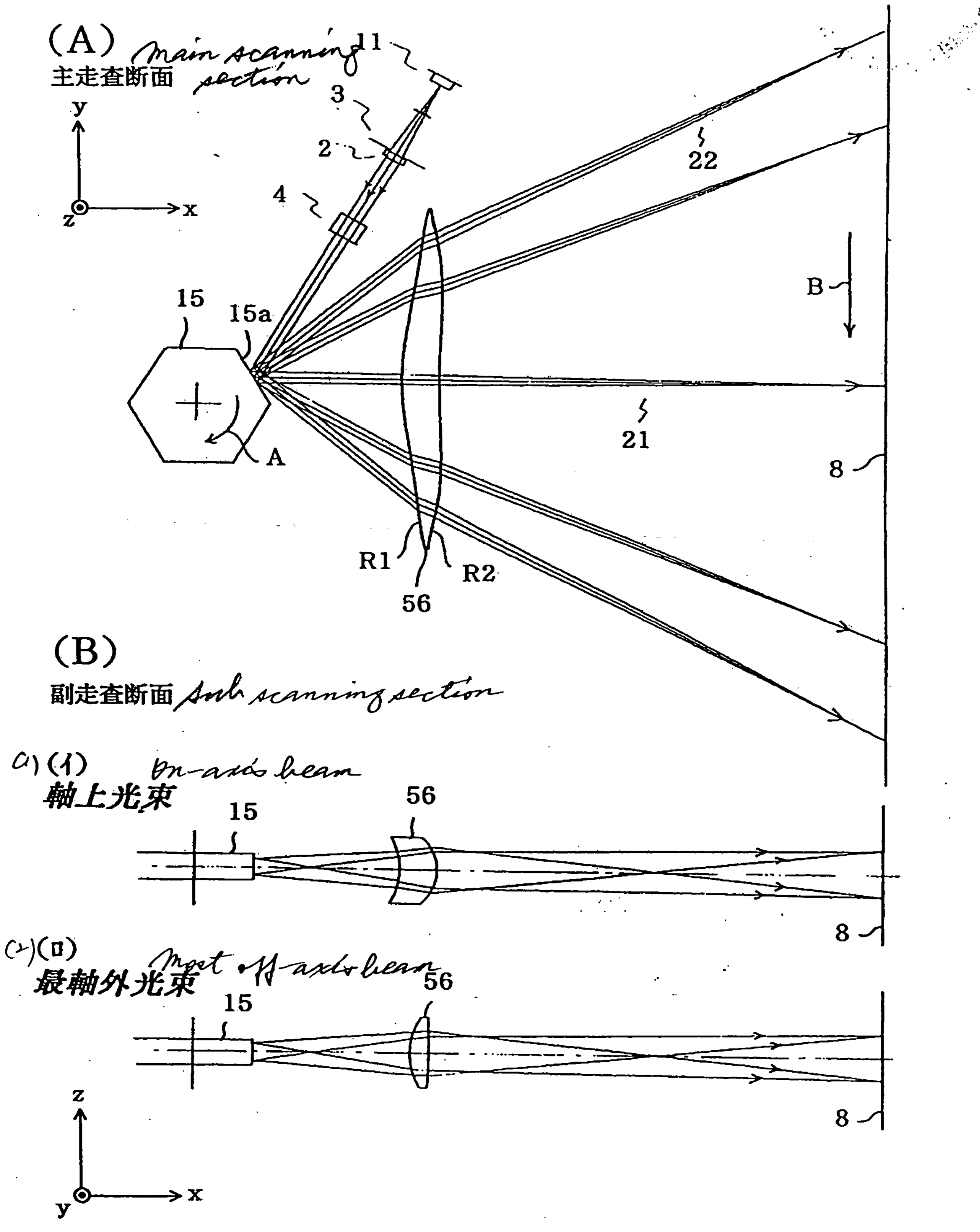


発光点1
発光点2
Light emitting point 1
Light emitting point 2
走査線曲がりU (um)
Curve of scanning line
像高 (mm)
Image height
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-120.0
-100.0
-80.0
-60.0
-40.0
-20.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0

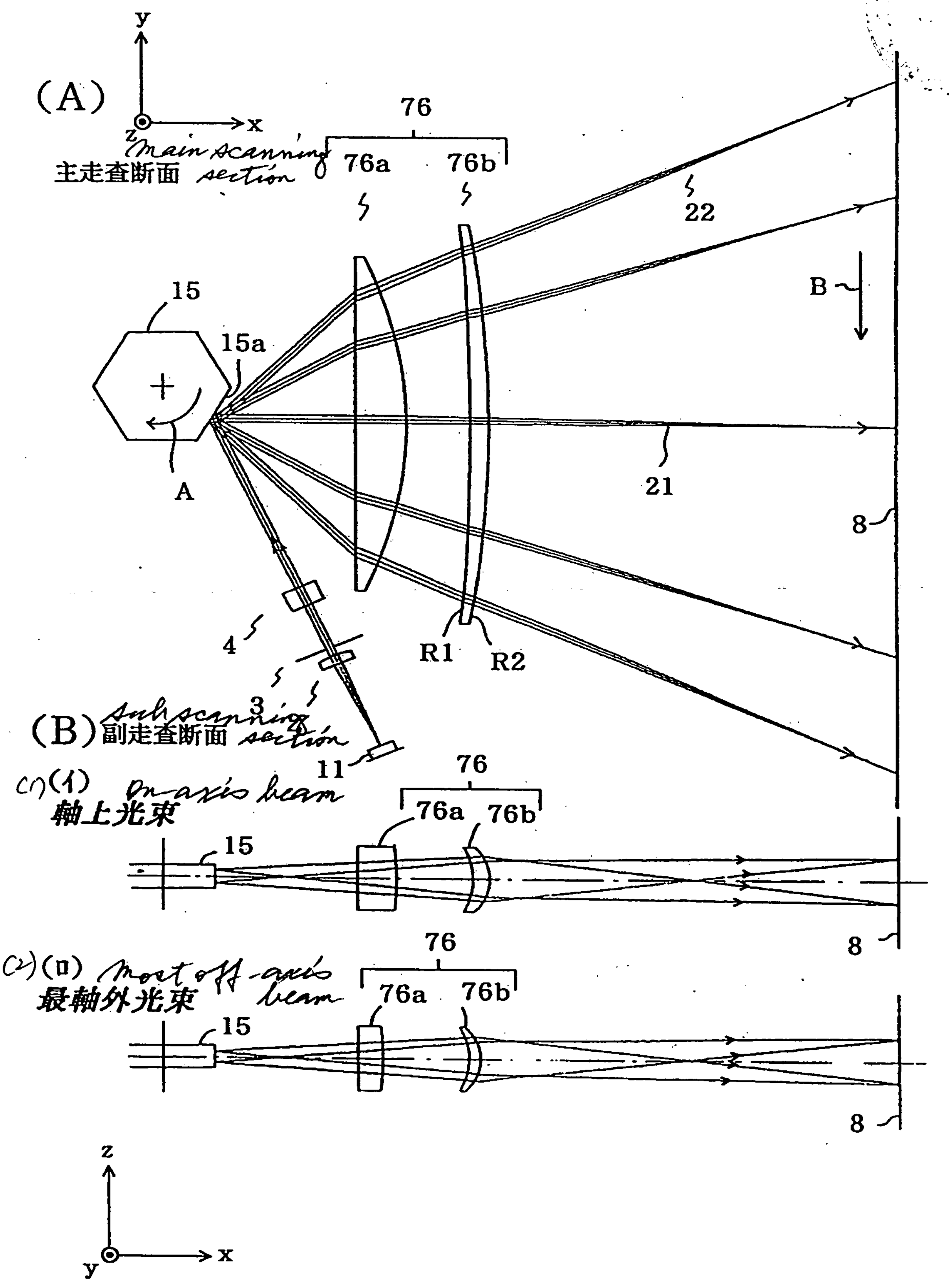
【図１３】 Fig. 13


(A)
主走査断面 main scanning section
11
2
3
4
y
x
z
5a
A
5
R1
R2
46
22
21
B
8
(B)
副走査断面 sub scanning section
(1) (イ) 軸上光束 on-axis beam
5
46
21
8
most off-axis beam
(2) (ロ) 最軸外光束
5
46
22
8
z
x
y

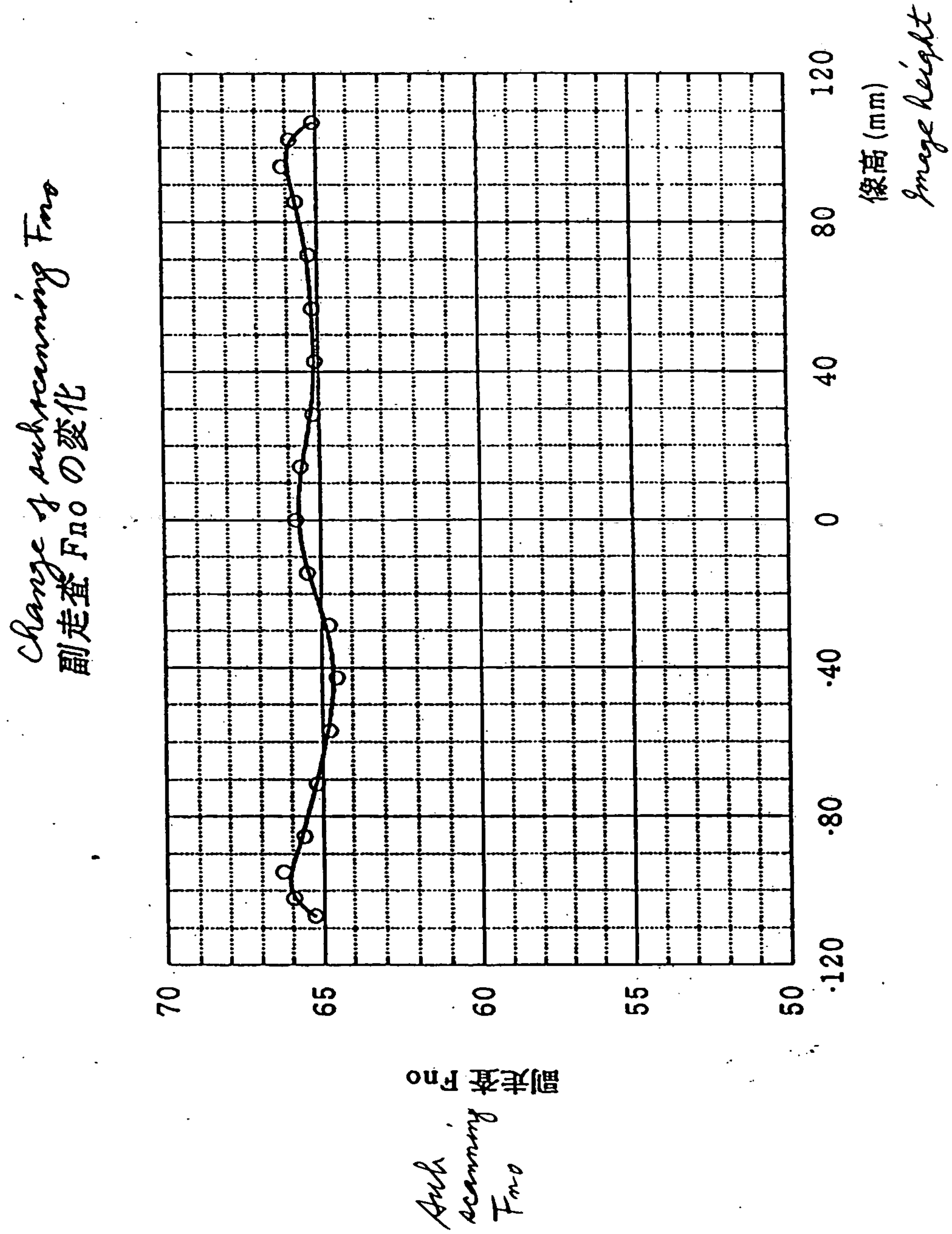
【図１４】 Fig. 14


(A)
主走査断面
main scanning section
11
3
2
4
15
15a
A
y
x
z
22
21
B
8
R1
R2
56
(B)
副走査断面
Sub scanning section
(1)(イ)
軸上光束
On-axis beam
15
56
8
(2)(ロ)
最軸外光束
Most off-axis beam
15
56
8
z
x
y

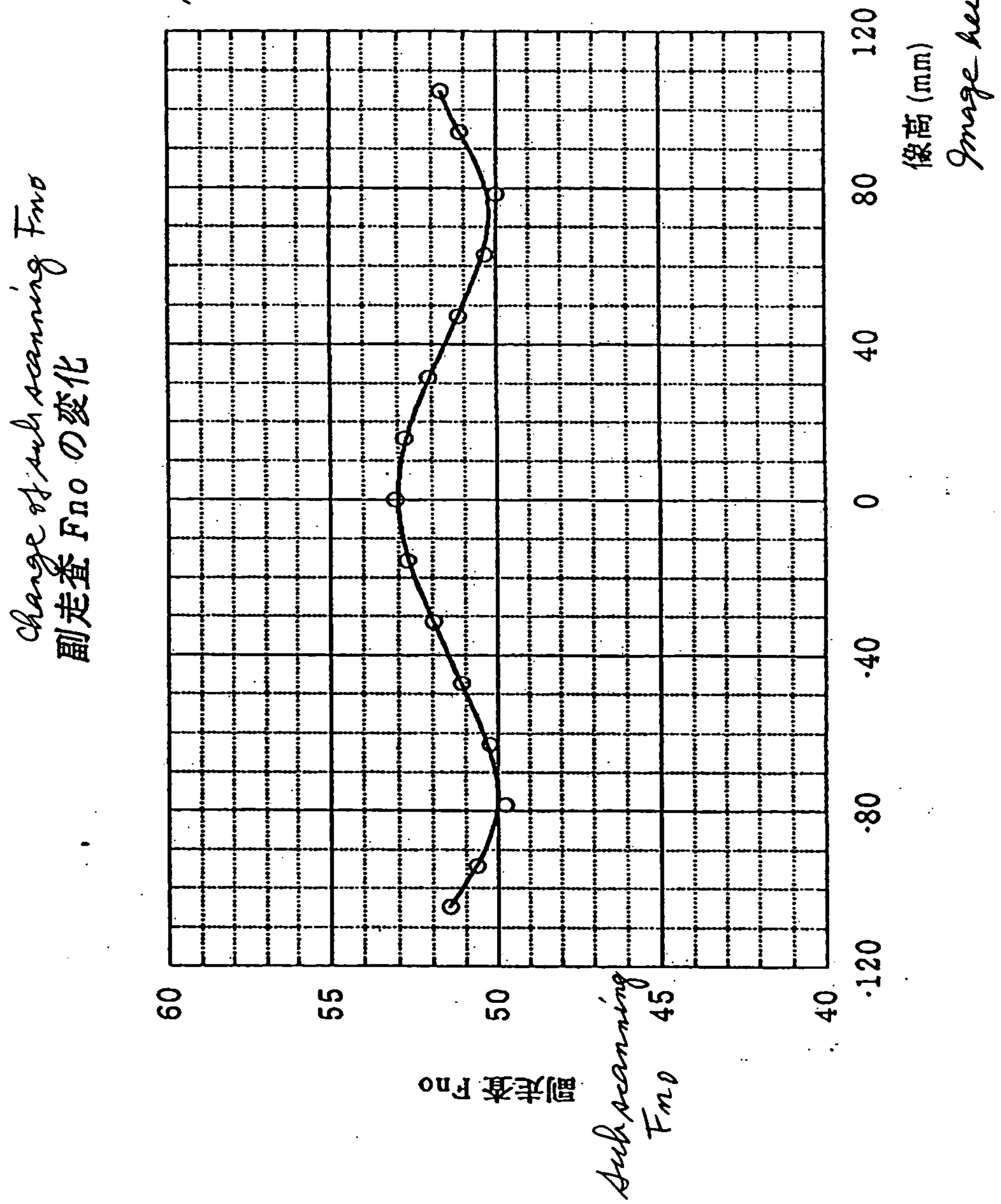
【図１５】 Fig. 15


(A)
y
x
z
main scanning section
主走査断面
76
76a
76b
22
15
15a
B
A
21
8
4
R1
R2
3
2
11
(B)
sub scanning section
副走査断面
(1)(イ) On-axis beam
軸上光束
76
76a
76b
15
8
(2)(ロ) Most off-axis beam
最軸外光束
76
76a
76b
15
8
z
y
x

【図１６】 Fig.16

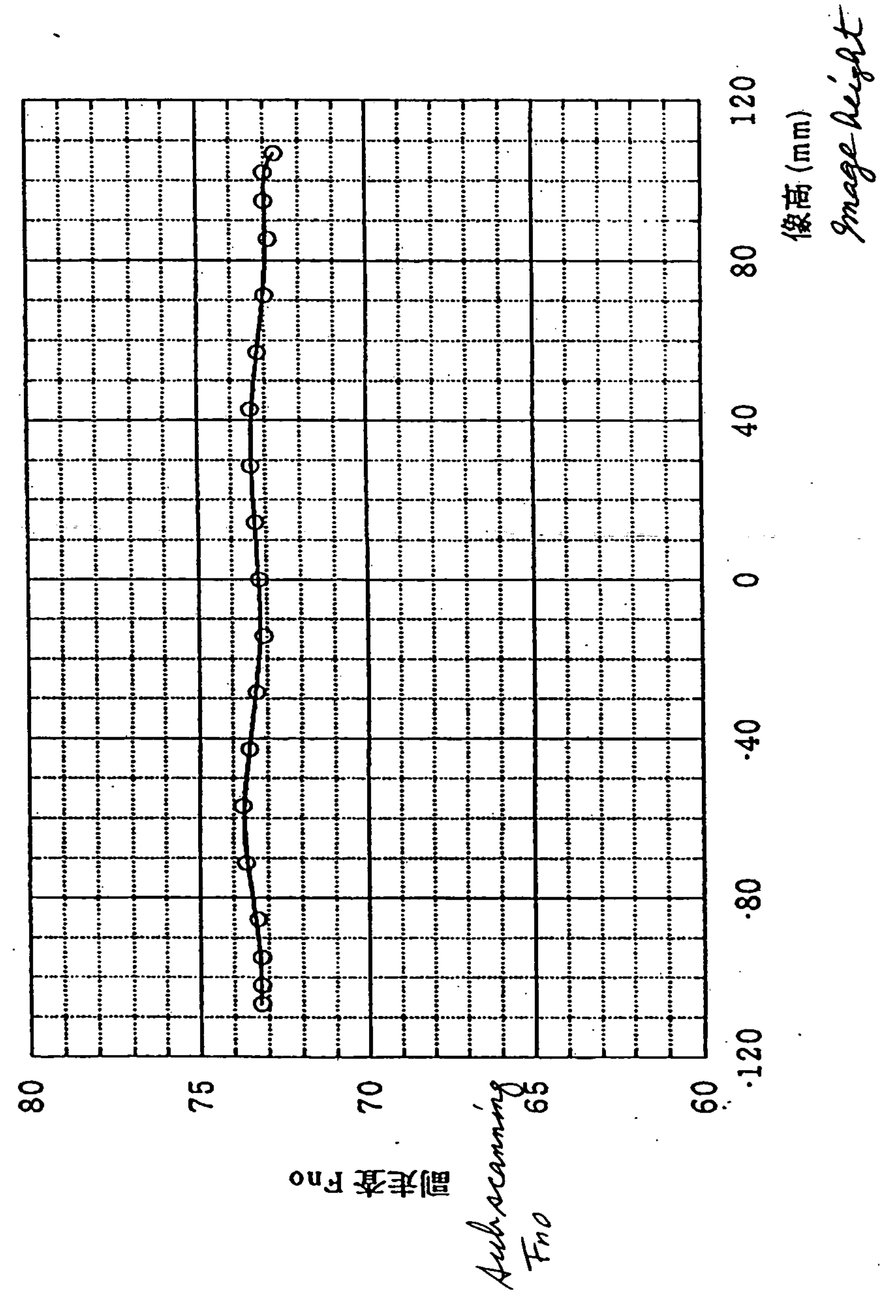

Change of subscanning Fno
副走査 Fno の変化
120
80
40
0
-40
-80
-120
像高 (mm)
Image height
70
65
60
55
50
副走査 Fno
Sub scanning Fno

【図１７】 Fig. 17

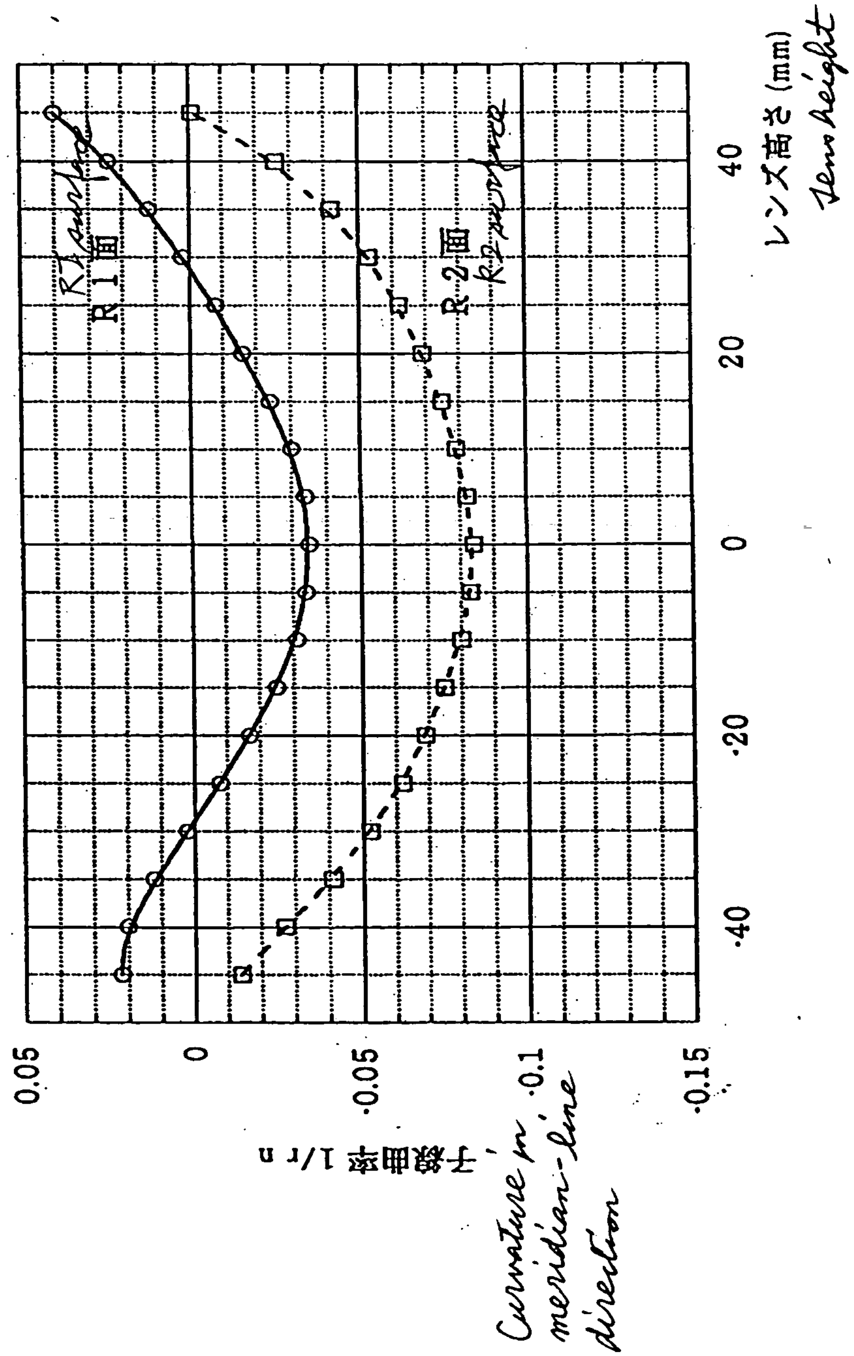

Change of sub scanning Fno
副走査 Fno の変化
60
55
50
45
40
-120
-80
-40
0
40
80
120
像高 (mm)
Image height
副走査 Fno
Sub scanning Fno

【図１８】 Fig.18

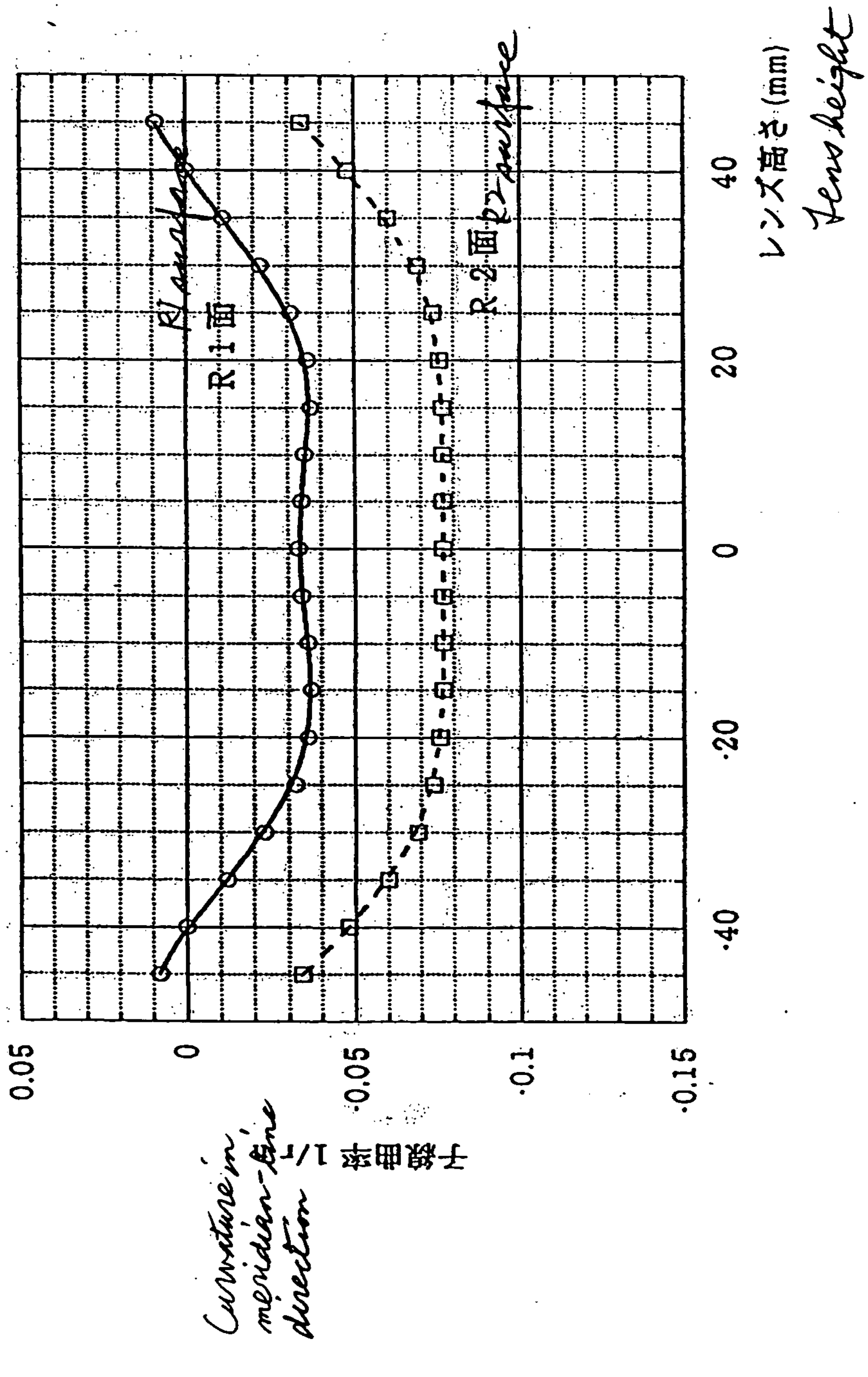
change of sub scanning Fno
副走査Ｆno の変化



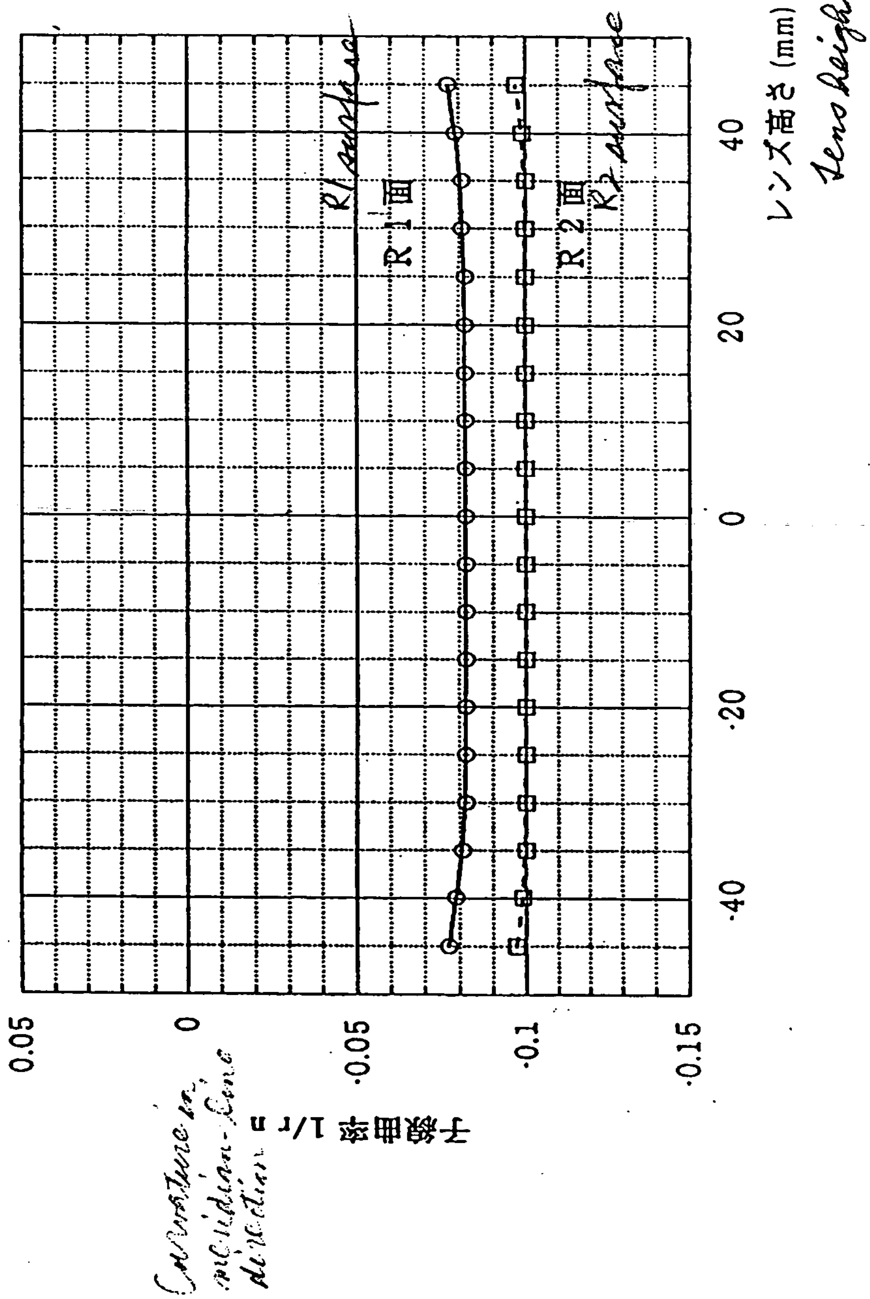
【図１９】 Fig. 19


R1面
R1 surface
R2面
R2 surface
レンズ高さ (mm)
lens height
40
20
0
-20
-40
0.05
0
-0.05
-0.1
-0.15
子線曲率 1/rn
Curvature in meridian-line direction

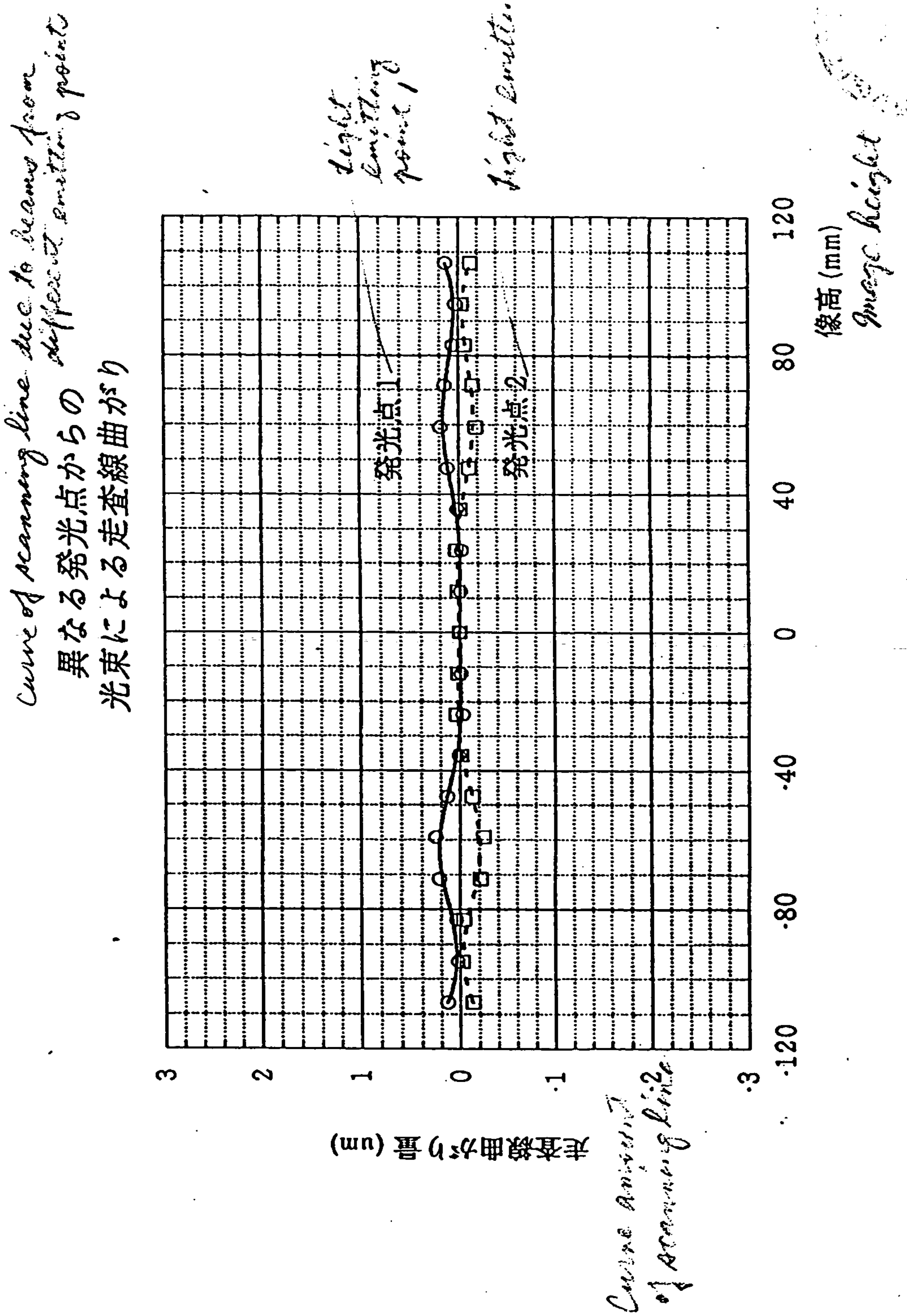
【図２０】 Fig 20


R 1面
R1 surface
R 2面
R2 surface
40
20
0
-20
-40
レンズ高さ (mm)
Lens height
0.05
0
-0.05
-0.1
-0.15
子線曲率 1/r
Curvature in meridian-line direction

【図２１】 Fig. 21

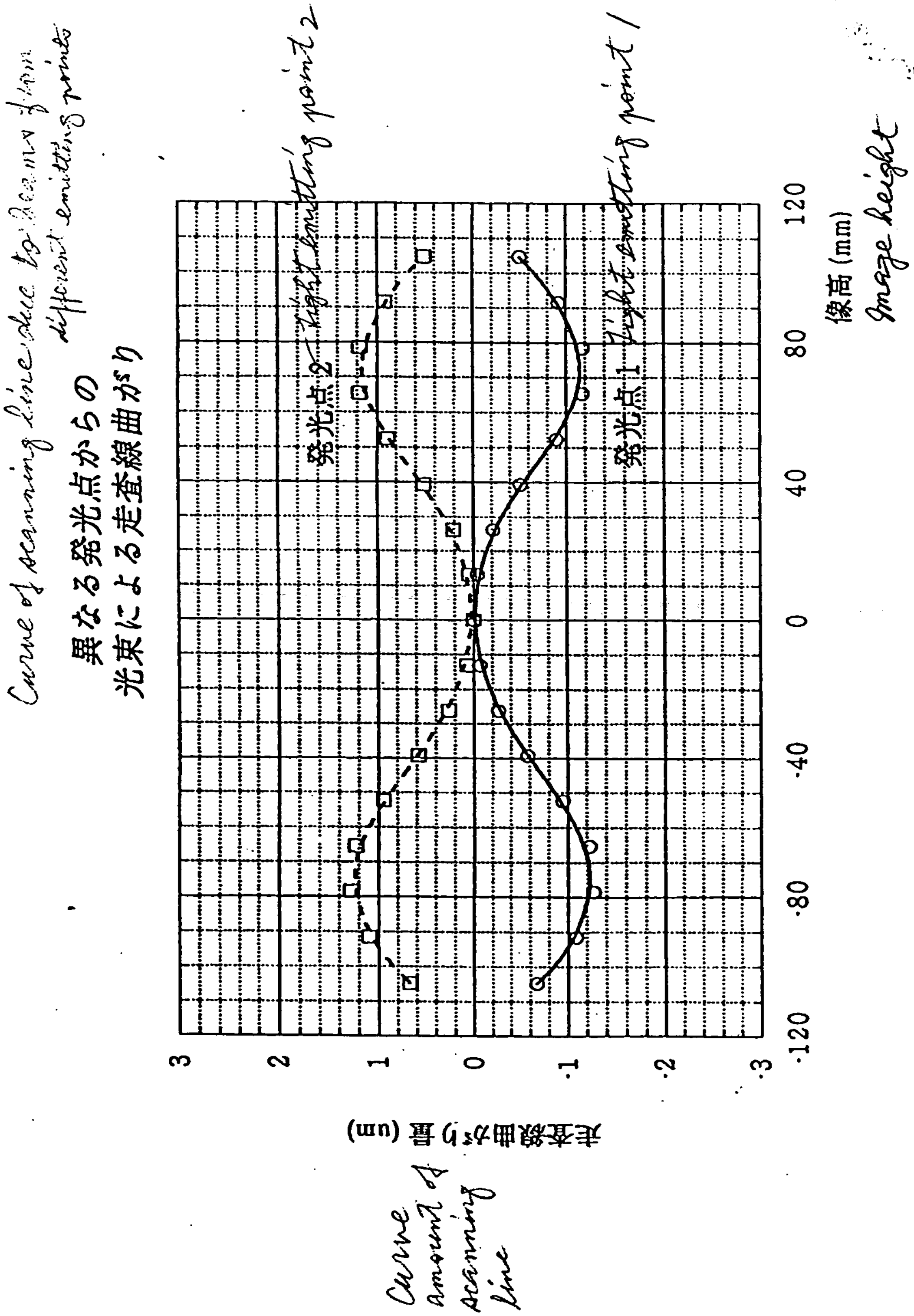

R 1 面
R1 surface
R 2 面
R2 surface
レンズ高さ (mm)
Lens height
40
20
0
-20
-40
0.05
0
-0.05
-0.1
-0.15
子線曲率 1/r n
Curvature in meridian-line direction

【図２２】 Fig, 22

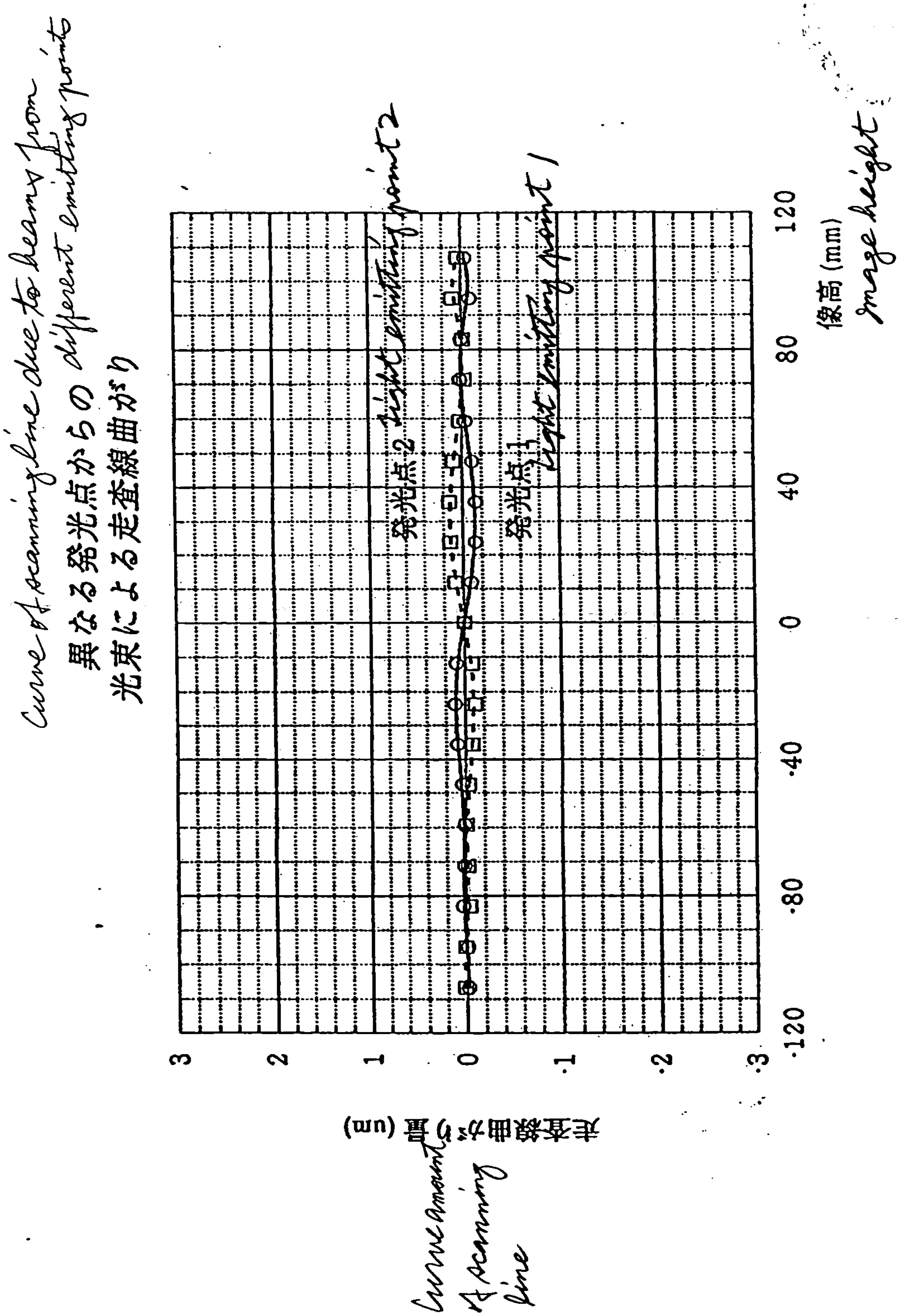


異なる発光点からの
光束による走査線曲がり
Curve of scanning line due to beams from different light emitting point
発光点1
Light emitting point 1
発光点2
Light emitting point 2
120
80
40
0
-40
-80
-120
像高(mm)
Image height
3
2
1
0
-1
-2
-3
走査線曲がり量 (um)
Curve amount of scanning line

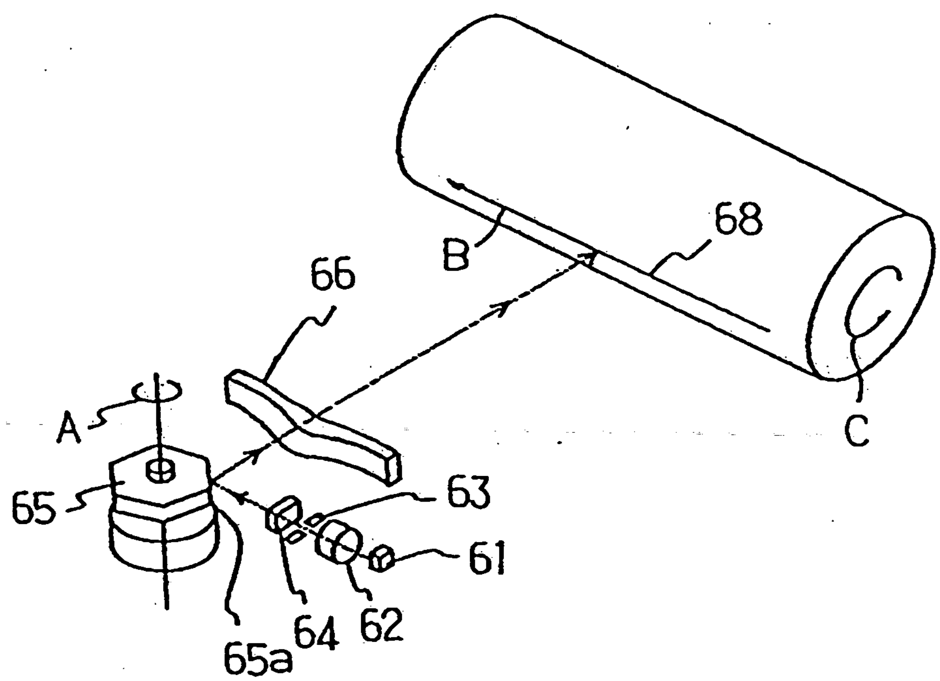
【図２３】 Fig. 23


異なる発光点からの
光束による走査線曲がり
Curve of scanning line due to beams from different emitting points
発光点2
Light emitting point 2
発光点1
Light emitting point 1
像高 (mm)
Image height
走査線曲がり量 (um)
Curve amount of scanning line
3
2
1
0
-1
-2
-3
-120
-80
-40
0
40
80
120

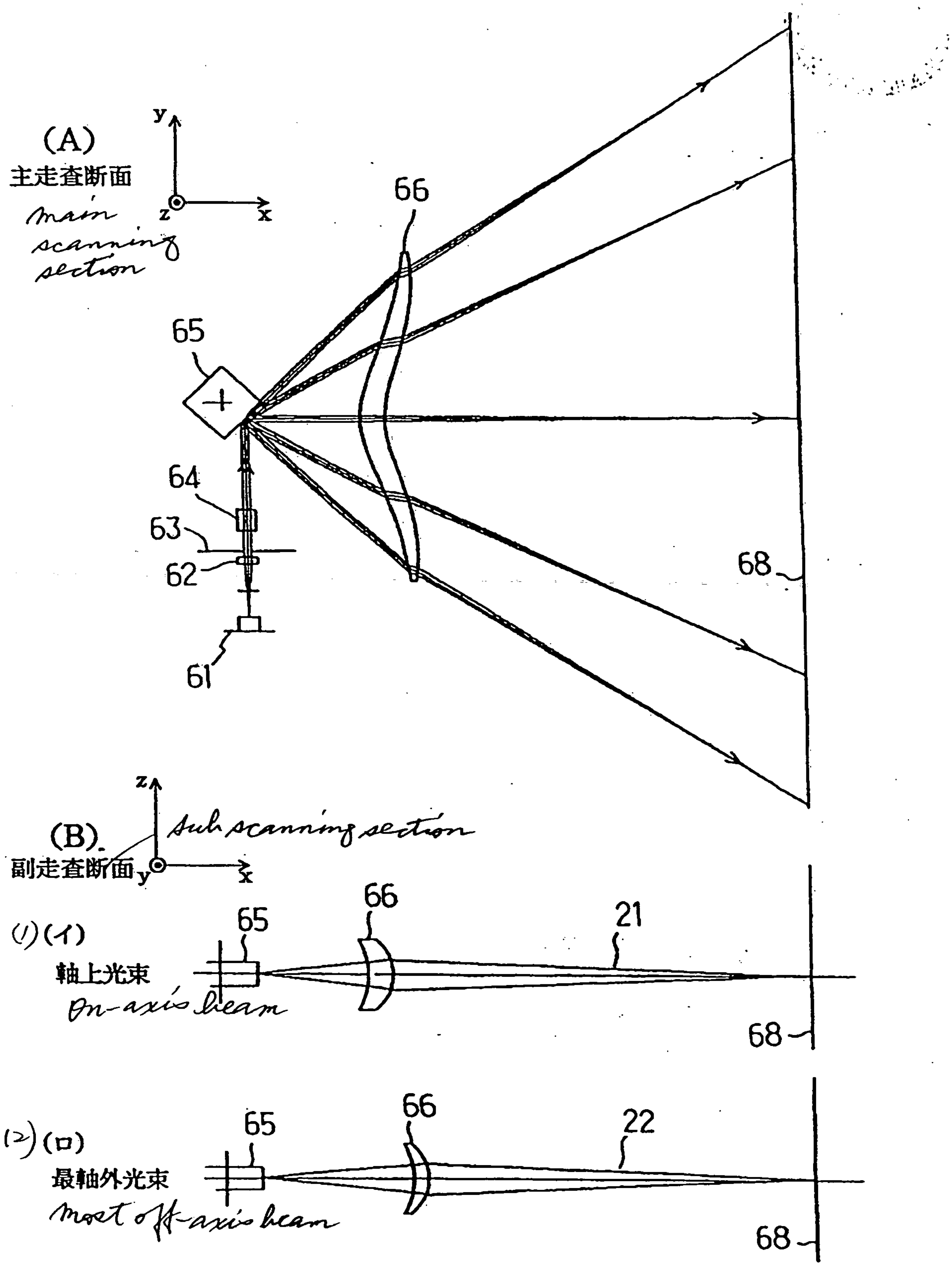
【図２４】 Fig. 24


異なる発光点からの
光束による走査線曲がり
Curve of scanning line due to beams from different emitting points
発光点2
light emitting point 2
発光点1
light emitting point 1
像高 (mm)
Image height
走査線曲がり量 (um)
Curve amount of scanning line
-120
-80
-40
0
40
80
120
3
2
1
0
-1
-2
-3

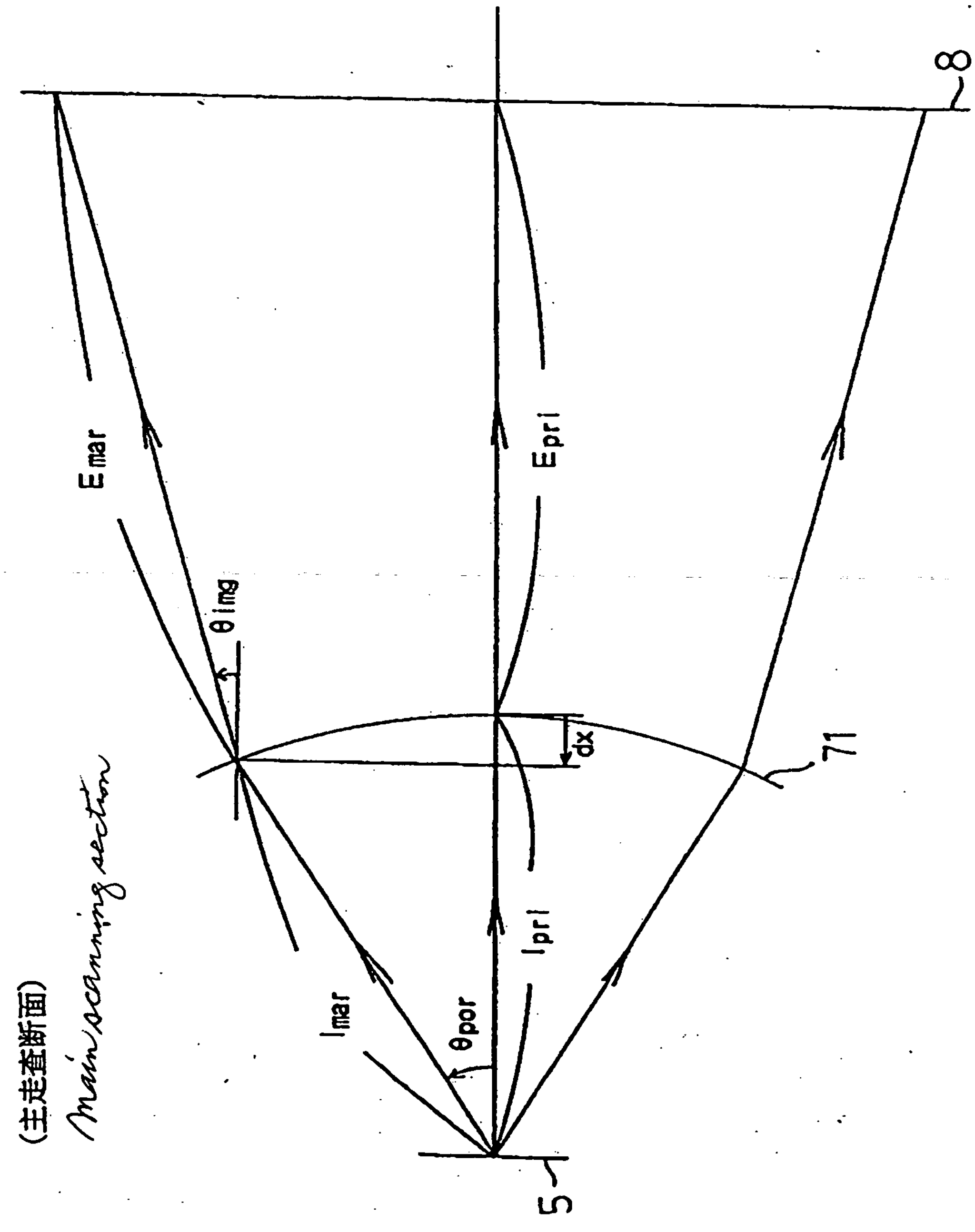
【図２５】 Fig. 25



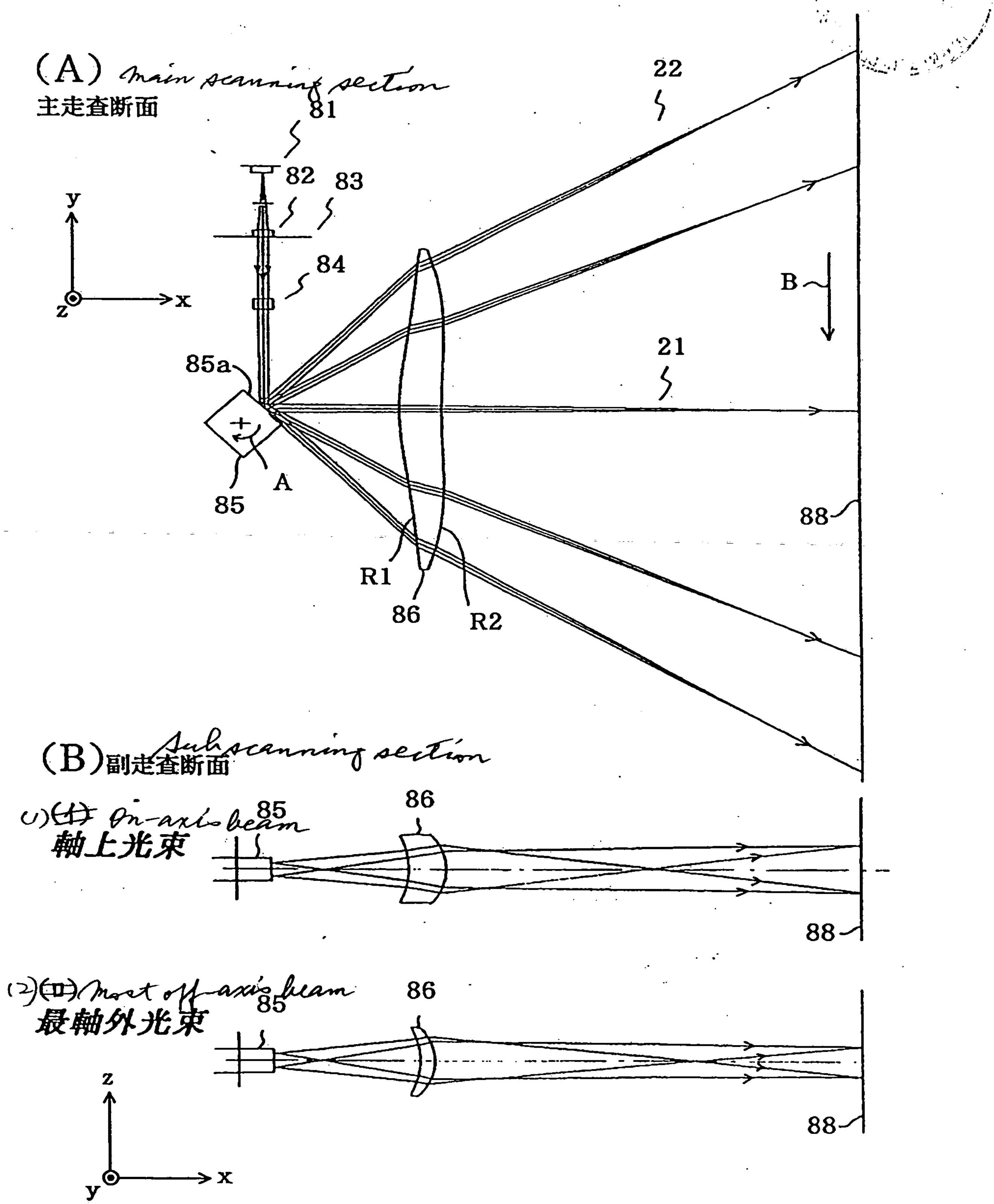
【図２６】 Fig. 26


(A)
主走査断面
main scanning section
y
z
x
66
65
64
63
62
61
68
(B)
副走査断面
Sub scanning section
z
y
x
(1)(イ)
軸上光束
On-axis beam
65
66
21
68
(2)(ロ)
最軸外光束
Most off-axis beam
65
66
22
68

【図２７】 Fig. 27

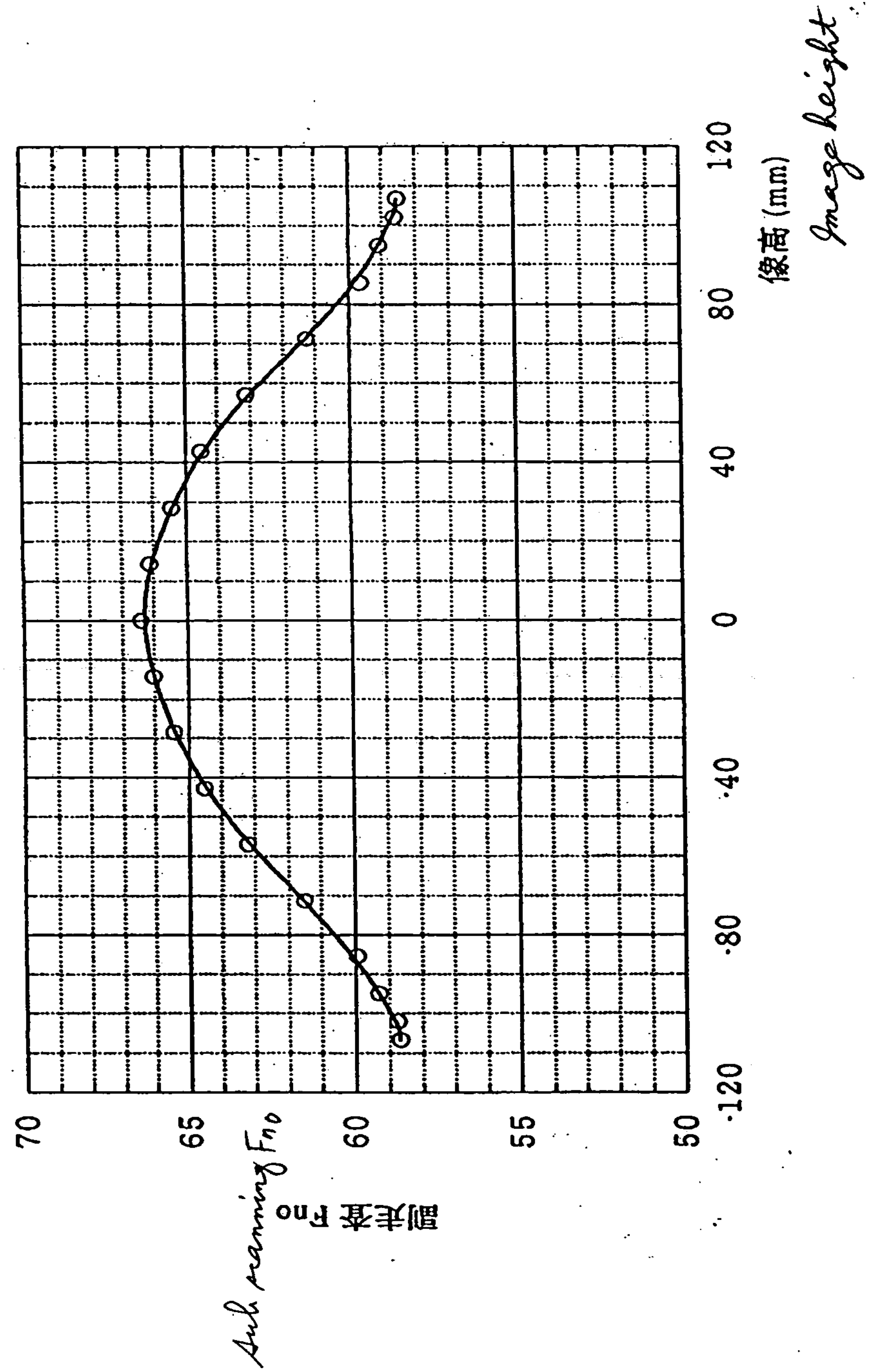

8
Emar
Epri
θimg
dx
71
Imar
θpor
Ipri
5
(主走査断面)
Main scanning section

【図２８】 Fig. 28

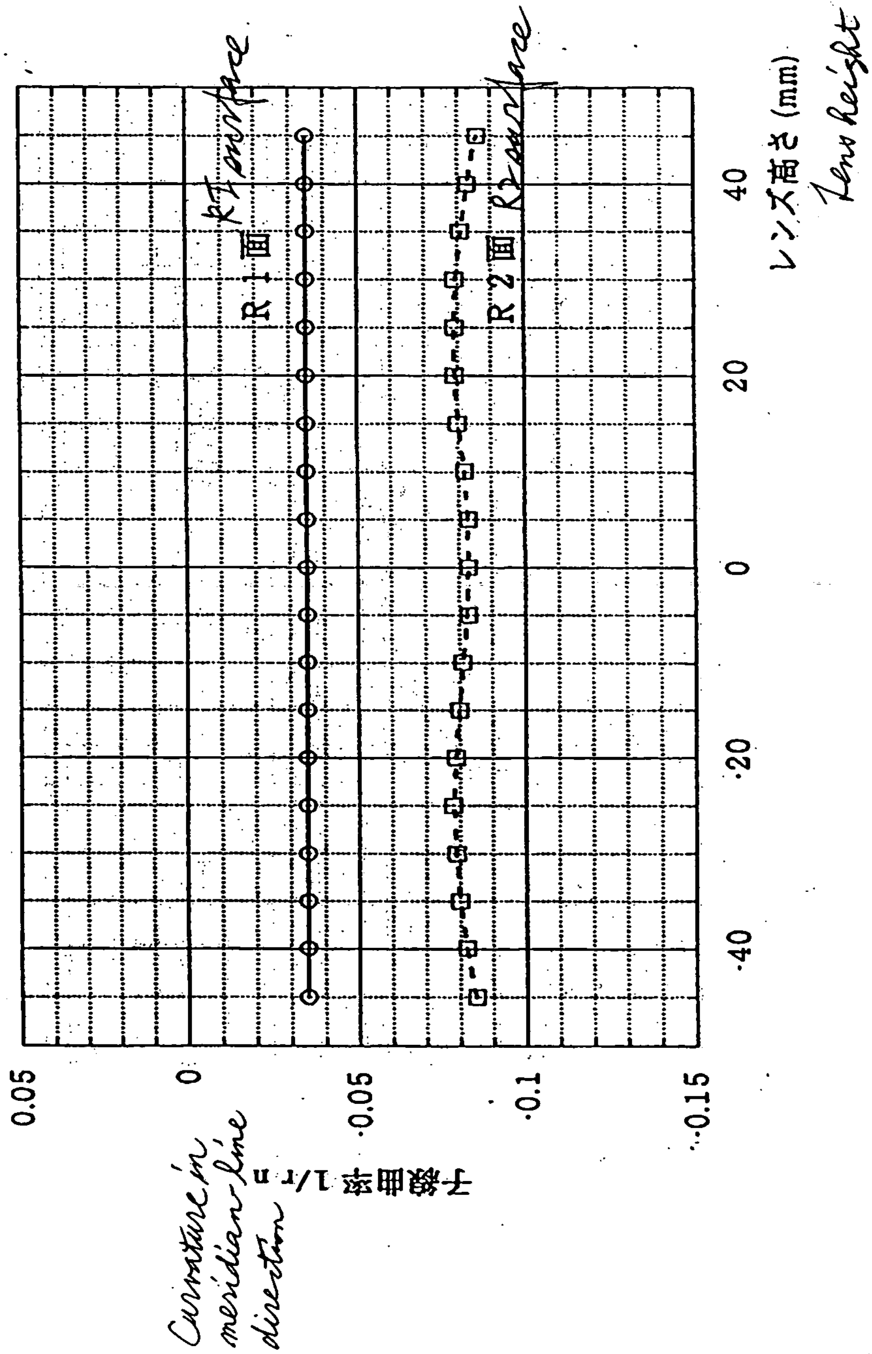

(A) main scanning section
主走査断面
81
82
83
84
85a
85
A
y
x
z
22
21
B
86
R1
R2
88
(B) 副走査断面 sub scanning section
(1) ~~(イ)~~ On-axis beam
軸上光束
85
86
88
(2) ~~(ロ)~~ most off-axis beam
最軸外光束
85
86
88
z
x
y

【図２９】 Fig.29

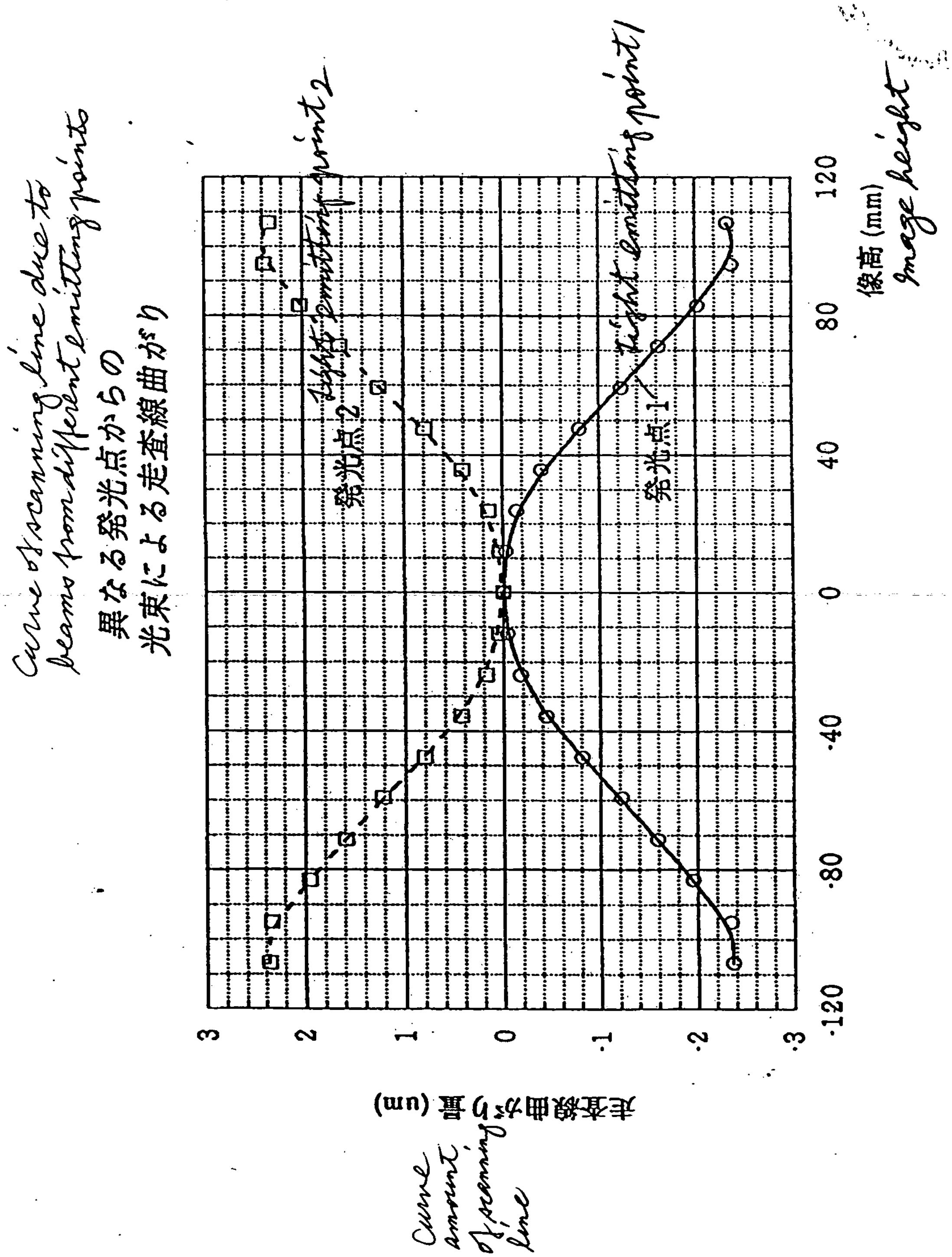
副走査 Fno の変化
Change of sub scanning Fno



【図３０】 Fig.30


R１面
R1 surface
R２面
R2 surface
レンズ高さ (mm)
Lens height
40
20
0
-20
-40
0.05
0
-0.05
-0.1
-0.15
子線曲率 1/rn
Curvature in meridian-line direction

【図３１】 Fig. 31


異なる発光点からの
光束による走査線曲がり
Curve of scanning line due to beams from different emitting points
発光点2
light emitting point 2
発光点1
light emitting point 1
像高 (mm)
image height
走査線曲がり量 (um)
Curve amount of scanning line
3
2
1
0
-1
-2
-3
-120
-80
-40
0
40
80
120

[Name of the Document] Abstract

[Abstract]

[Object] An object of the present invention is to obtain a compact scanning optical apparatus and multibeam scanning optical apparatus suitable for highly accurate printing by setting the shape of a single fθ appropriately.

[Means for Achieving the Object] In a scanning optical apparatus in which a beam of light emitted from a light source means is imaged into a linear shape long in the main scanning direction on a deflecting surface of a deflecting element through a first optical element and a second optical element and the beam of light deflected by the deflecting element is imaged into a spot-like shape on a surface to be scanned through a third optical element so as to scan the surface to be scanned, the third optical element comprises a single lens, the both lens surfaces of the single lens comprise a toric surface of an aspherical shape in the main scanning plane, and the curvature of the lens surfaces of the single lens in the sub scanning plane is continuously varied from the on-axis toward the off-axis in an effective portion of the lens, thereby suppressing a change of the F number in the sub scanning direction due to the image height of the beam

of light incident on the surface to be scanned.

[Elected Drawing] Figure 1

[Name of the Document]	Authorized Correction Data
[Document to be corrected]	Patent Application

<Recognition Information·Additional Information>

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